Lower and upper troposphere CH4 and CO concentrations retrieved from IASI data.

Leonid Yurganov[1,2]

Ira Leifer[2]

1) University of Maryland Baltimore County, MD
2) Bubbleology Research International, Solvang, CA

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Outline

A goal of this research is to explore a feasibility of Thermal Infrared (TIR) spectrometers to measure concentrations of trace gases and their anomalies in the Lower Troposphere (LT). We define LT as a layer between the surface and altitude 600 hPa (~4 km). Empirical sensitivity of IASI CH4 data obtained by **NUCAPS** to this layer was estimated using comparisons with regular direct aircraft sampling at three NOAA/ESRL sites located in the USA. The rest of the report presents **some examples** of results based on NUCAPS 1.0 retrievals.

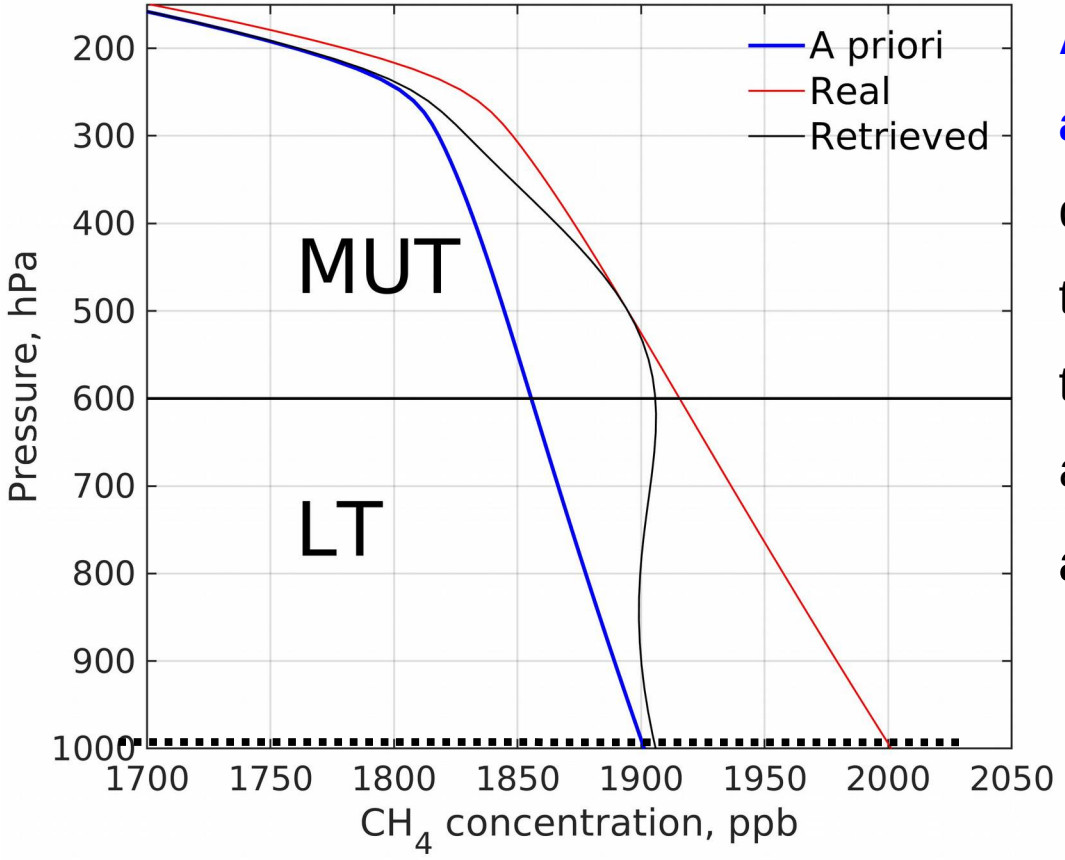
1) Trends of IASI CH4 in the Arctic were compared with NOAA/ESRL surface data.

2) Maps of Arctic IASI CH4: anomaly spatial patterns and seasonal cycles

3) USA IASI CH4 data: IASI vs Pacific and vs GOSAT

4) IASI CO and CH4 data for Siberian fires of 2012

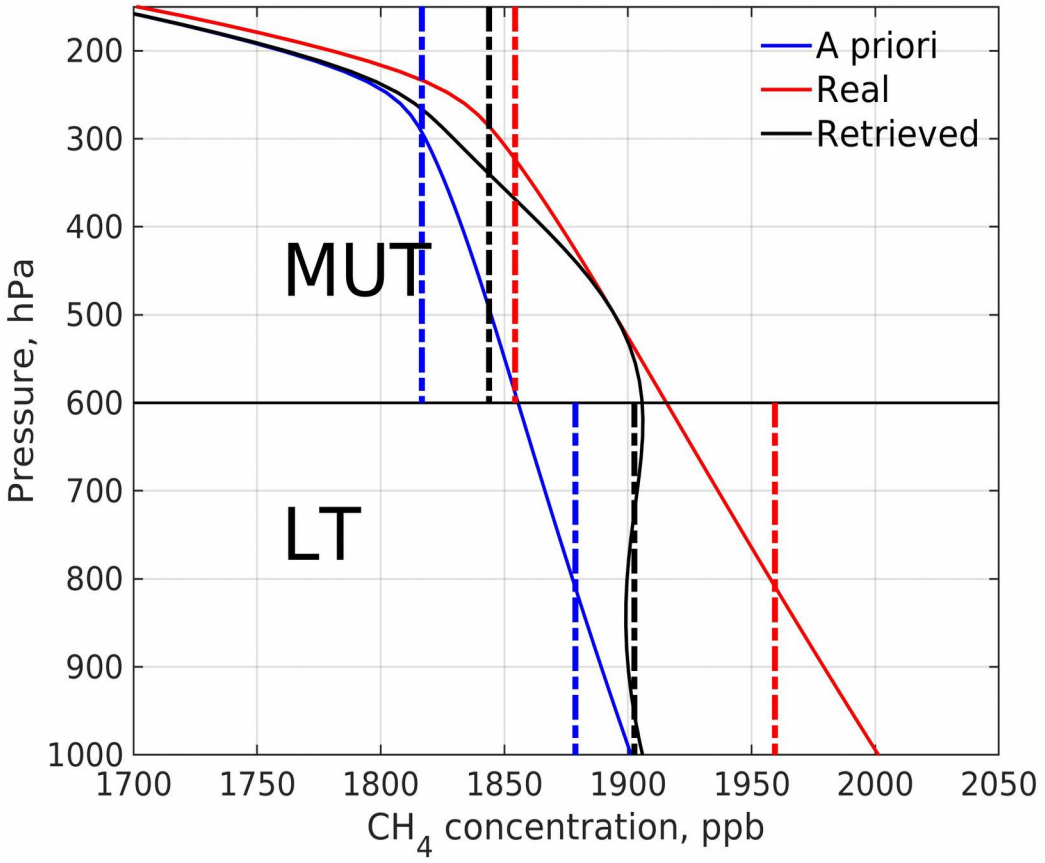
Retrieval techniques usually require a priori (1st guess) profile. A deviation of gas profile from the apriori is retrieved with a **bias** that changes wkith altitude. **Averaging kernel (AK) matrix** describes a sensitivity of each level to each level. **AK** is calculated using a Radiation Transfer model, but **not suplied by NUCAPS**.



A priori (blue line, the profile assumed for NUCAPS v1) is preset as depending on the latitude only, i.e., there is no seasonal cycle and longer-term trend in it. **"Real" profile (red line)** and **"retrieved" profile (black line)** are **arbitrary** and shown just for illustration.

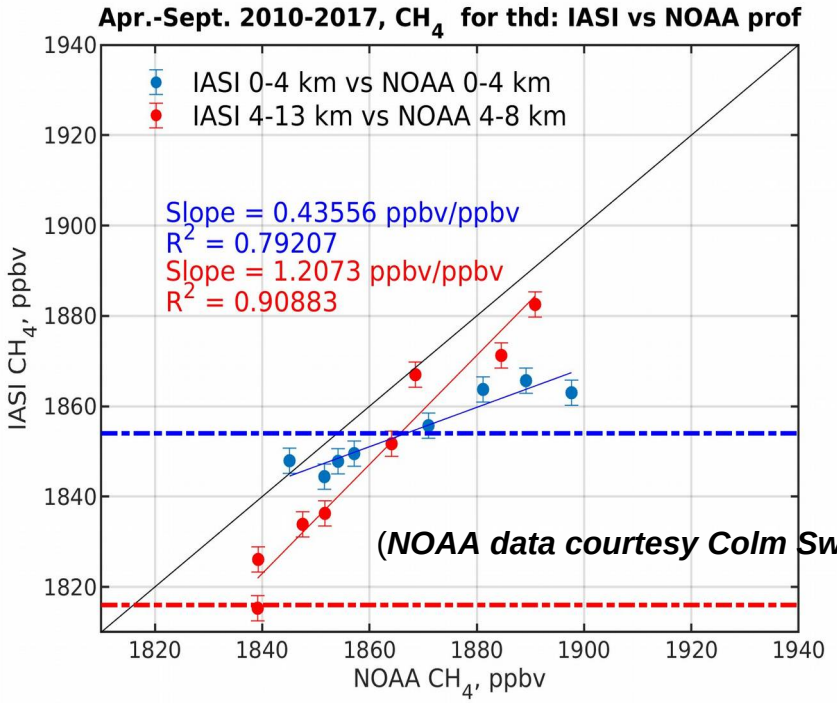
Alternatively, the sensitivity may be assessed empirically. We estimated the sensitivity using aircraft measurements between the surface and altitude 8 km.

Concentrations were averaged over LT an MUT and compared with concentrations measured from an aircraft.

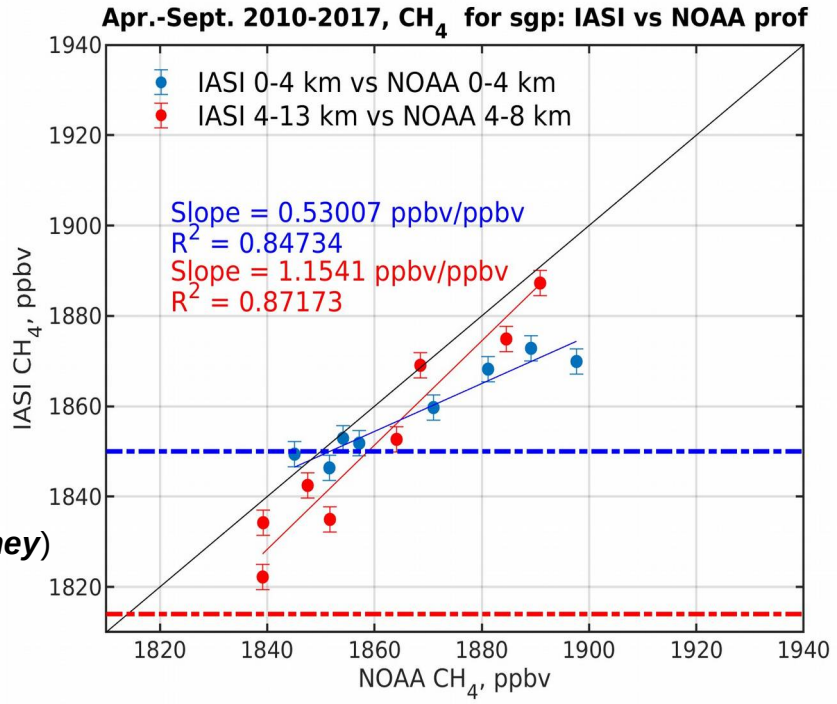


The concentrations were averaged for altitudes, the warmer period of the year, and compared with corresponding in situ NOAA sampling (next slide)

IASI vs NOAA/ESRL aircraft sampling (red = mid-upper troposphere, MUT, blue = lower troposphere LT)

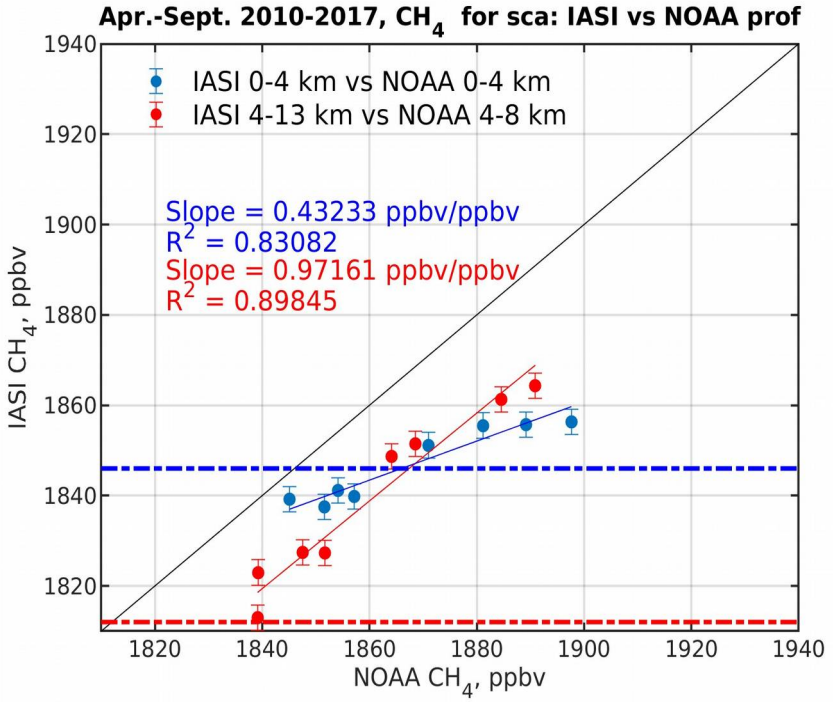


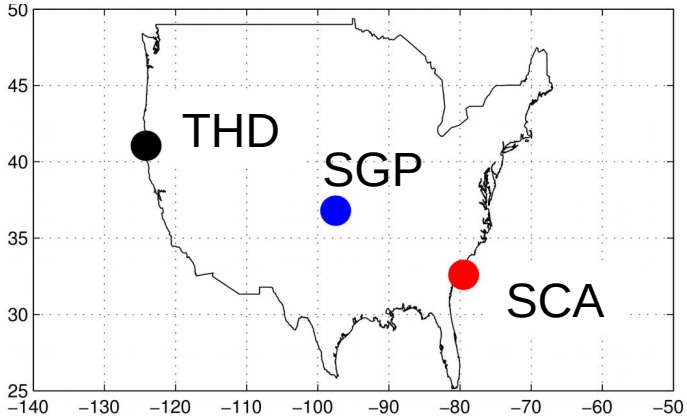
(***NOAA data courtesy Colm Sweeney***)



A priori LT

A priori MUT





(***NOAA data courtesy Colm Sweeney***)

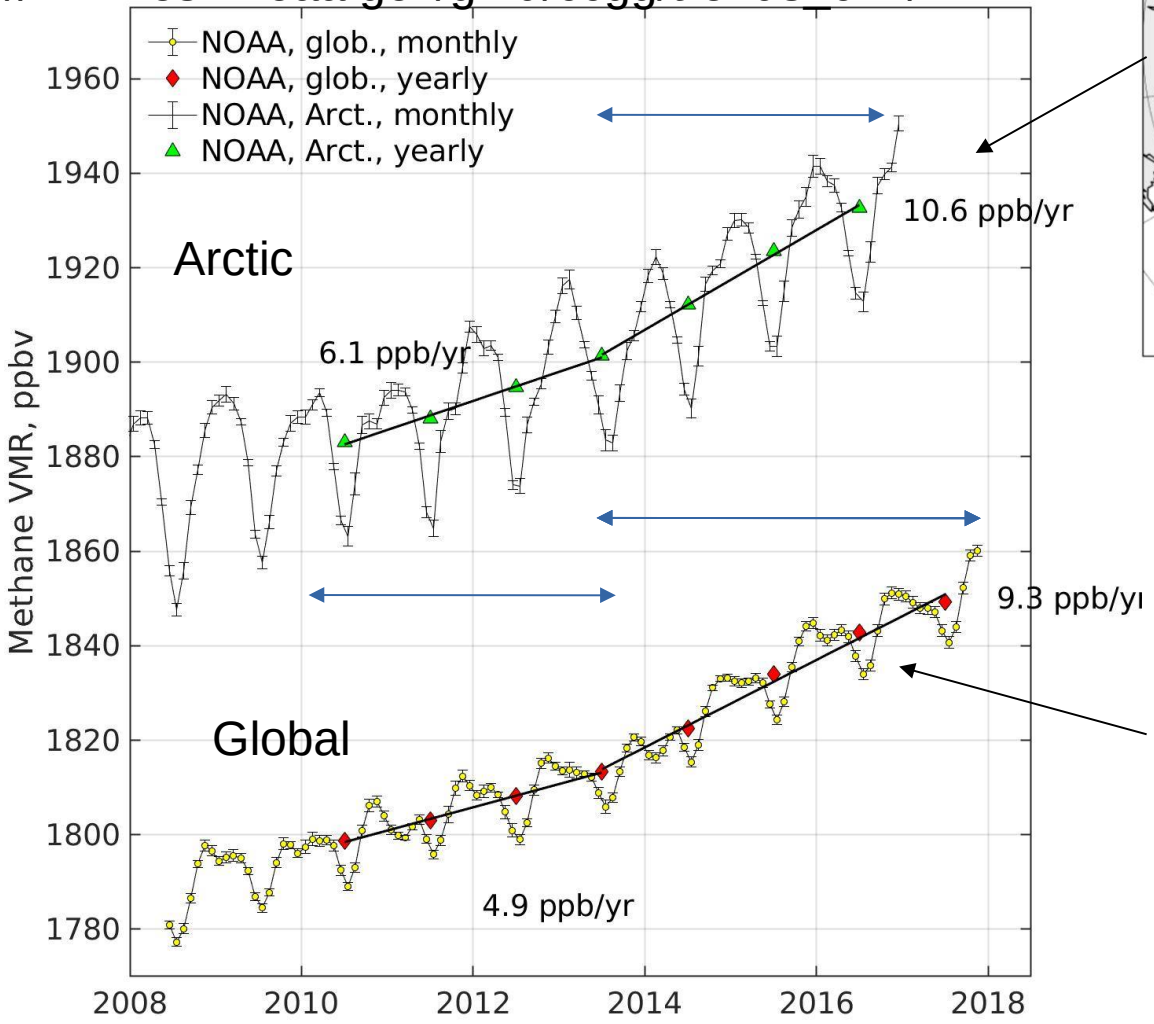
Mean slopes (**empirical sensitivity**)
MUT: **1.11** ± 0.12 ppbv(IASI)/ppbv(true)
LT: **0.46** ± 0.06 ppbv(IASI)/ppbv(true)

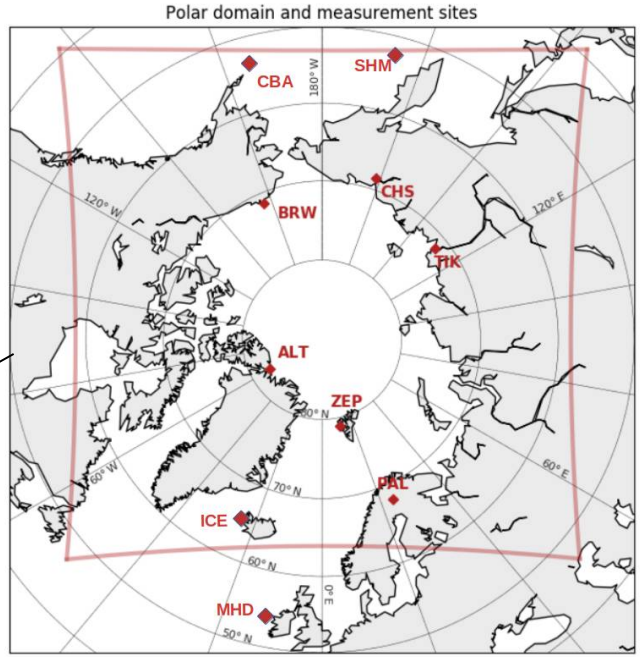
(***Yurganov et al., 2018, submitted***)

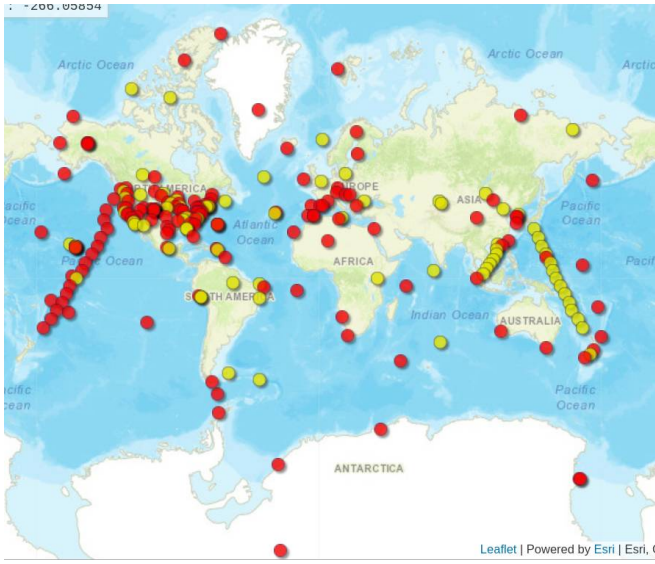
Example One: methane trends, a problem of its acceleration

NOAA/ESRL surface Arctic and global CH4 trends

https://www.esrl.noaa.gov/gmd/ccgg/trends_ch4/





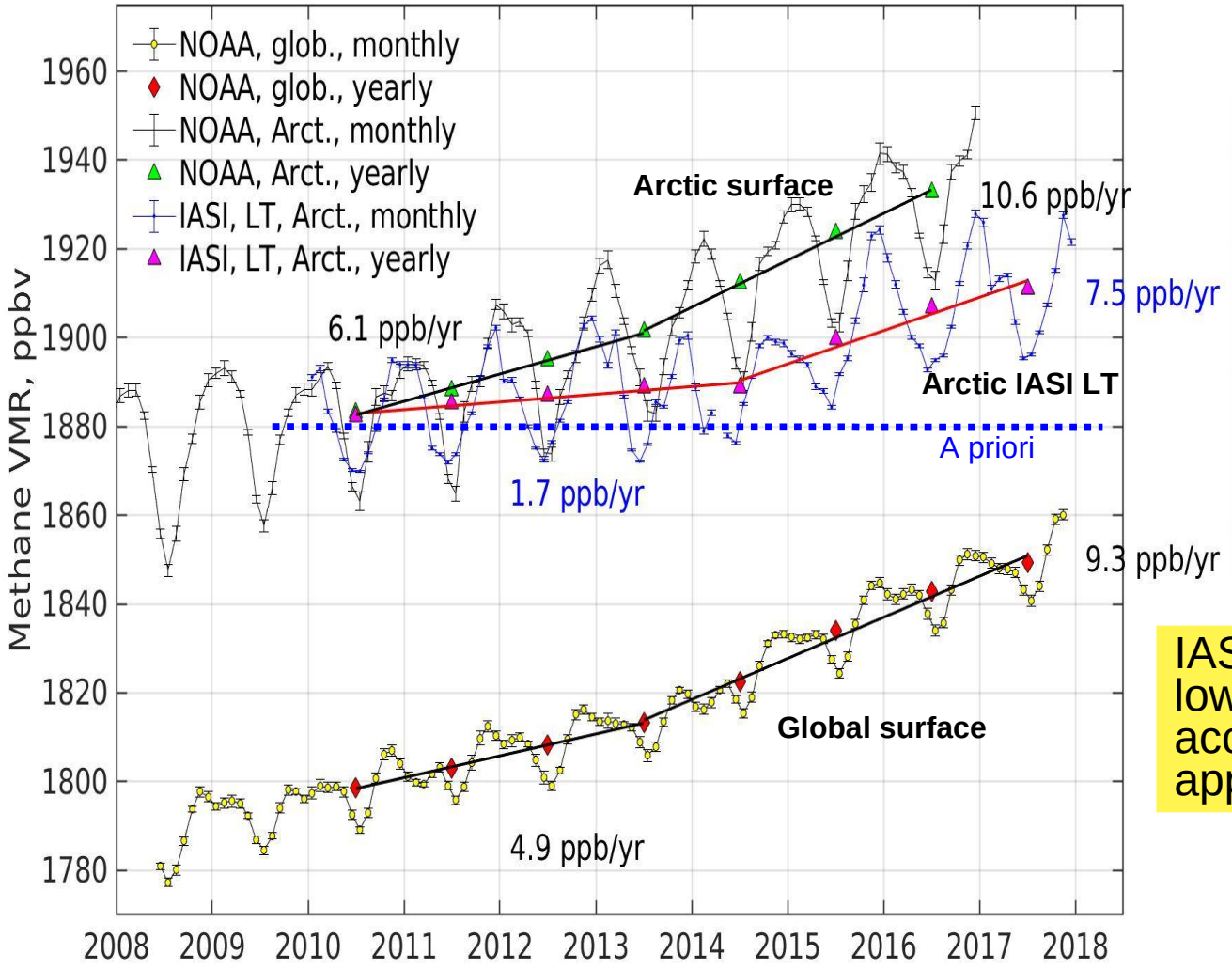


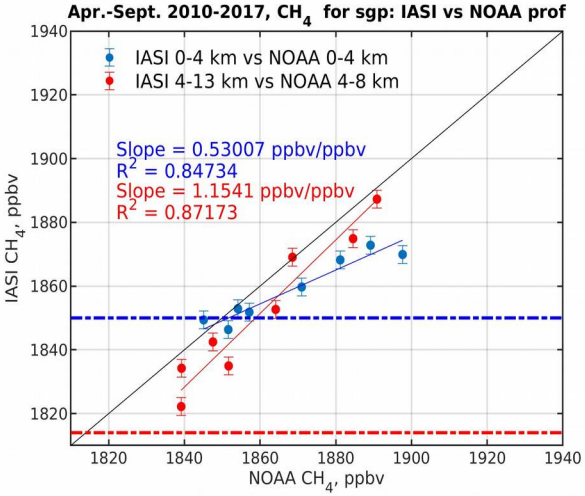
NOAA/ESRL surface monthly CH4 for Arctic and global

PLUS Low Trop. IASI zonal Arctic (50° N – 85° N)

Arctic **LT IASI methane** is growing slower than **surface NOAA**

methane in agreement with validation



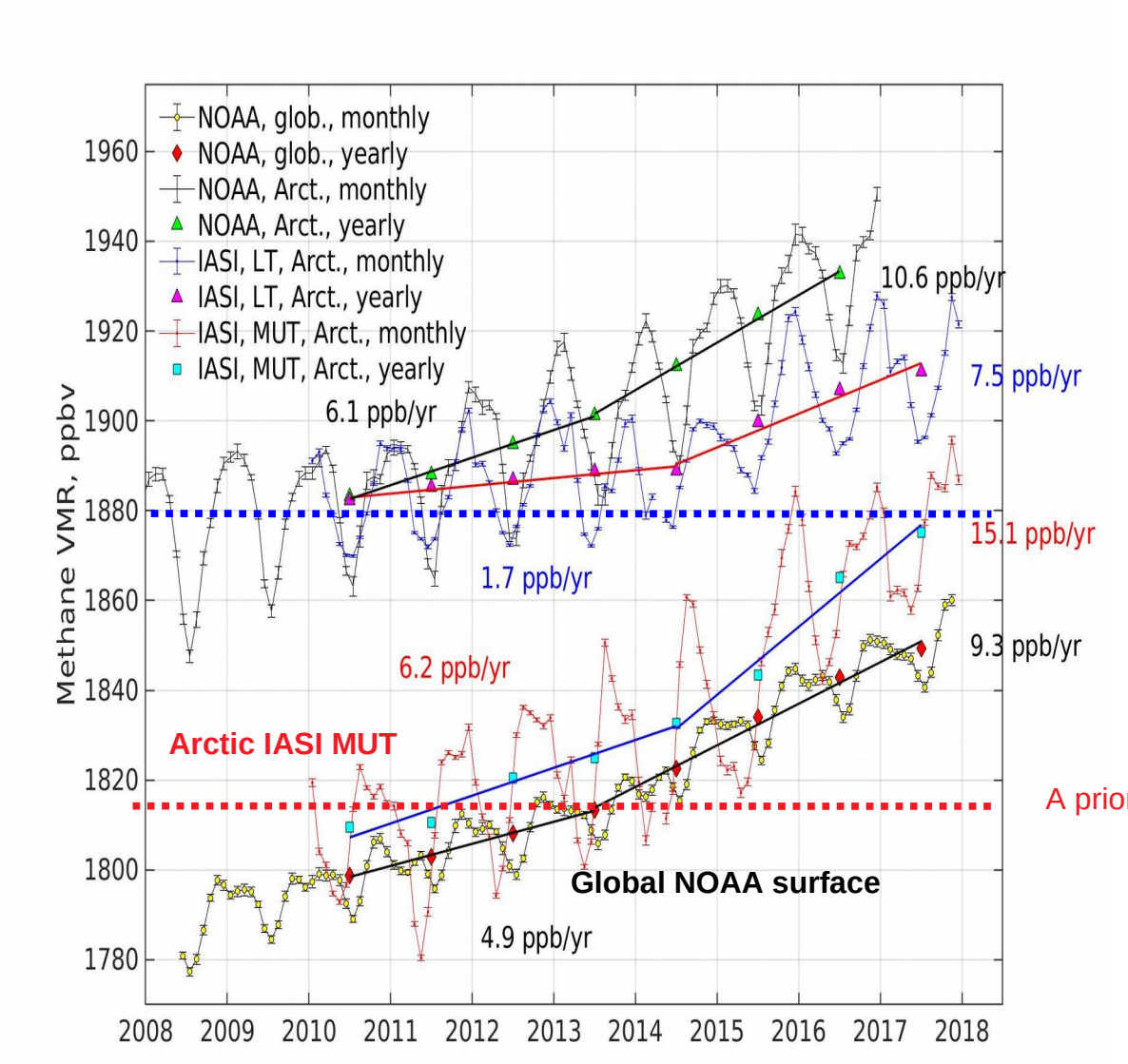


IASI LT data are usable if the lower sensitivity is taken into account and correction is applied if it is possible.

NOAA/ESRL surface monthly CH4 for Arctic and global

PLUS Low Trop. IASI zonal Arctic

PLUS Mid-Upper Trop. IASI zonal Arctic



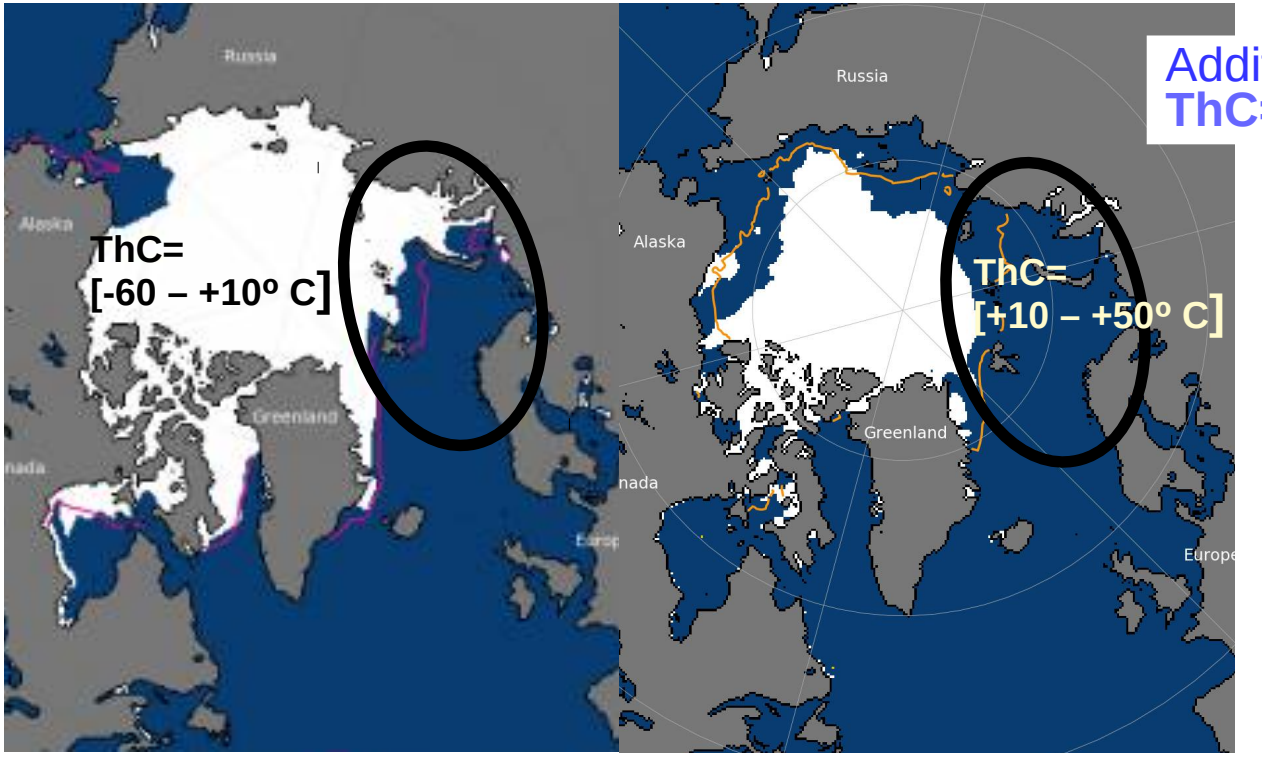
Arctic MUT IASI methane is growing with the same rate or even faster than the surface NOAA methane in agreement with validation.

A faster growing (<u>15 vs 11 ppb/yr and 9 ppb/yr)</u> may be explained by inclusion of the sea data (next slide).

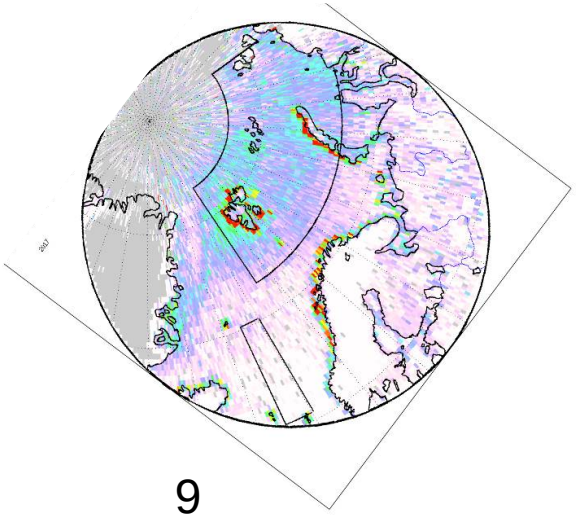
Example Two: Arctic LT and MUT in summer and winter.

The Arctic specifics is the **Polar night** (November- February) when the Sun is under horizon and only the outgoing **Thermal IR radiation is available** for satellites. However, the surface of thick sea ice cools down dramatically and the **sensitivity to LT drops down** too. Fortunately, the Barents Sea and partially the Kara Sea **(BKS)** stay free of ice and the IASI sensitivity to methane at vast areas keeps high almost year-round.

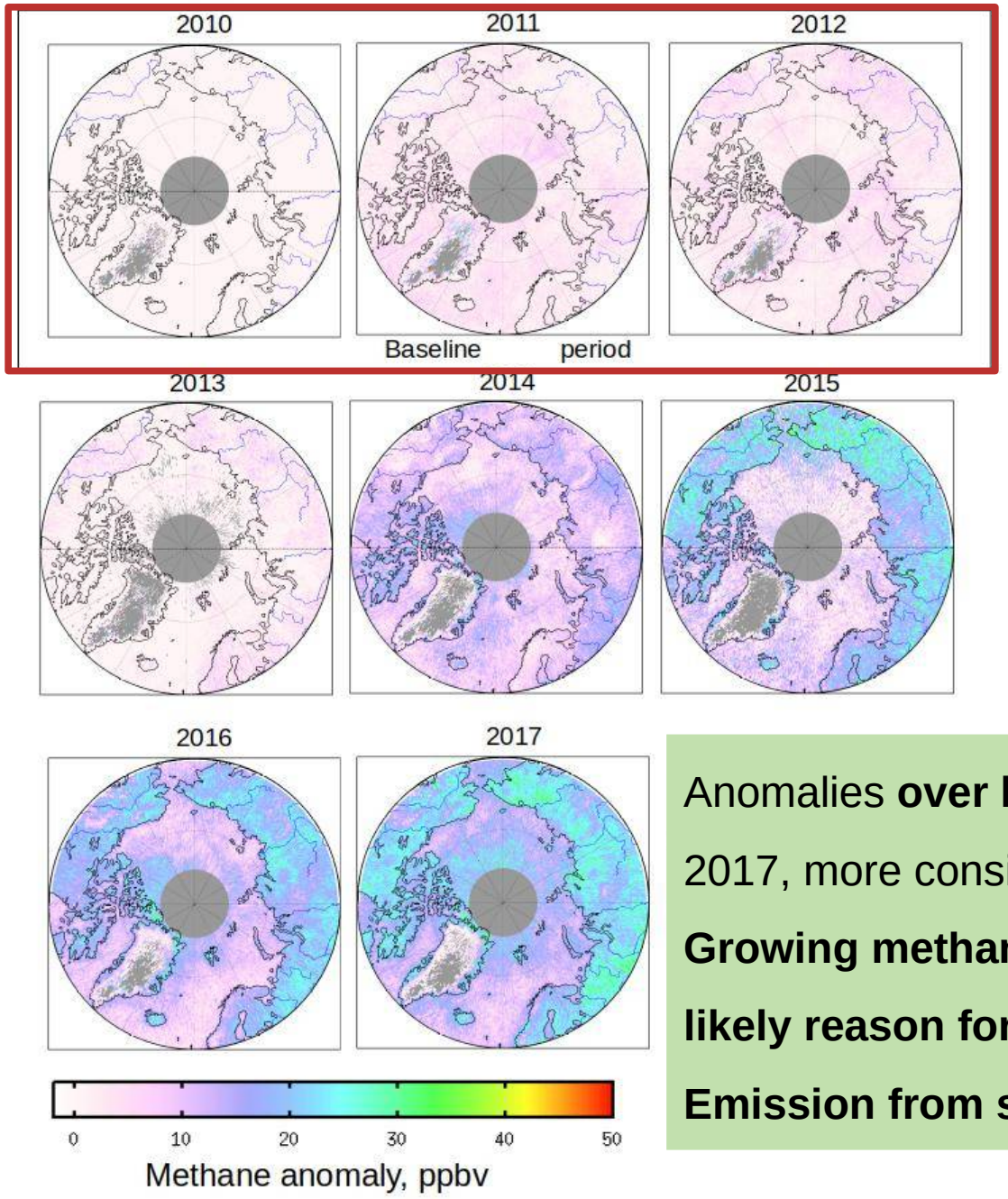
November 2017 **August 2018**



Additional QC flag, **Thermal Contrast**:
ThC=T(surface) – T(600 hPa) > 10ºC



Low tropospheric IASI methane anomaly over Arctic in summer (June-September). Baseline period: 2010-2012.

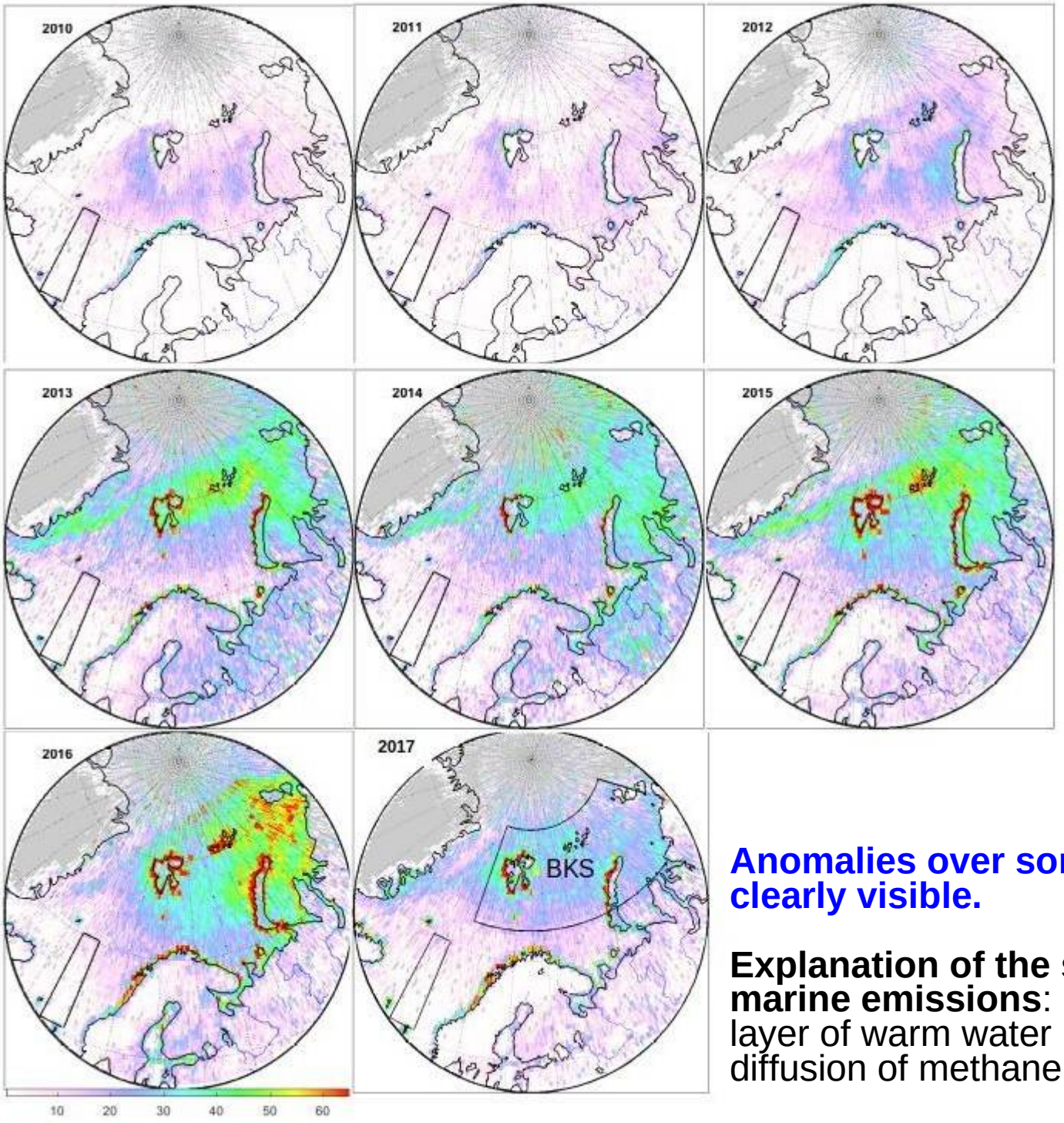


Each 0.5^0x0.5^0 grid cell is a difference between the mean summer CH4 for the year and that for period 2010-2012.

Anomalies **over land** increased from 0 to 25 ppbv in 2017, more considerably than those over sea.

Growing methane emission from land is the most likely reason for growing anomaly in summer.

Emission from sea looks negligible.



Fall-Winter

(November-December)

IASI CH4 anomaly for BKS

Anomalies of LT methane are referenced to the N. Atlantic polygon (shown on the maps).

The anomalies increased from 15 ppbv to 60+ ppbv in 2016-2017

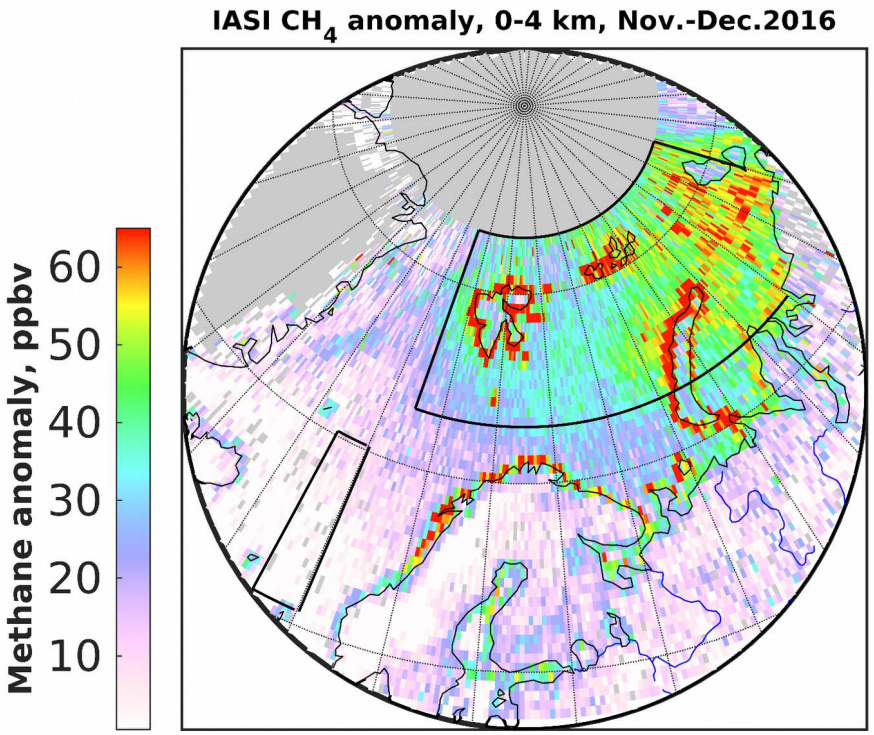
Anomalies over some spots at BKS are clearly visible.

Explanation of the seasonal changes in the marine emissions: in summer the surface layer of warm water (thermocline) blocks diffusion of methane from the seabed.

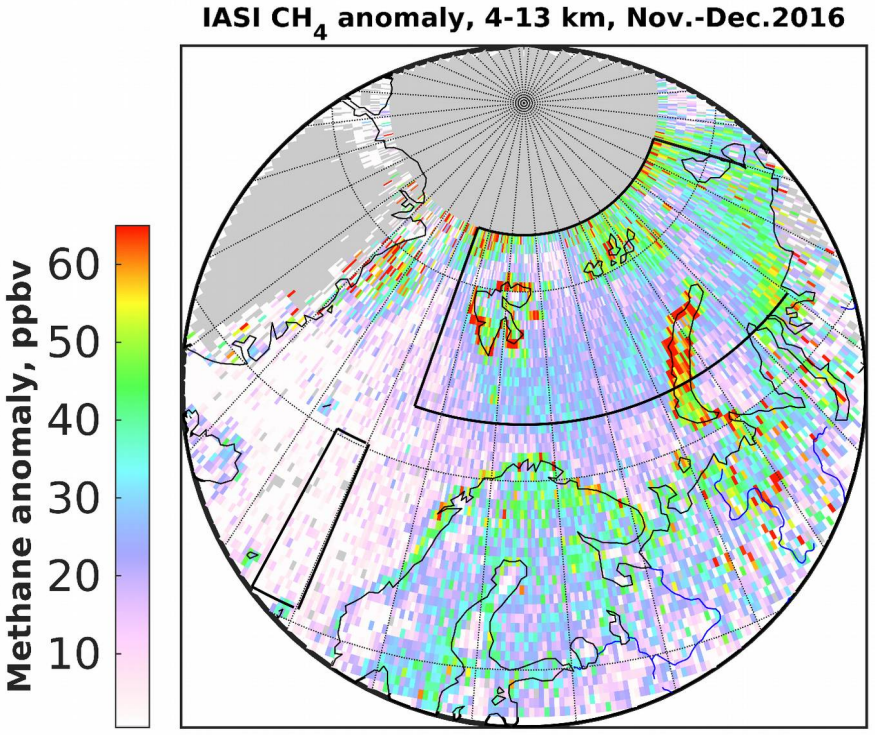
Comparison of LT and MUT methane anomalies

(November-December 2016)

LT



MUT



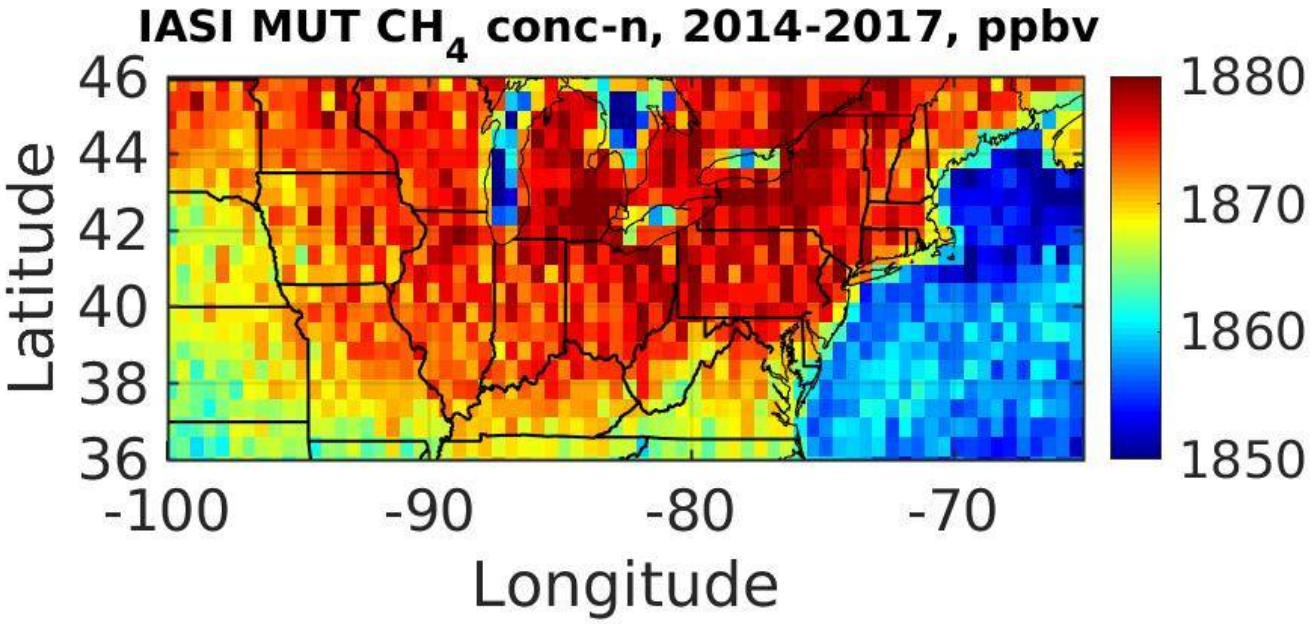
Low tropospheric IASI data may help in location of methane sources.

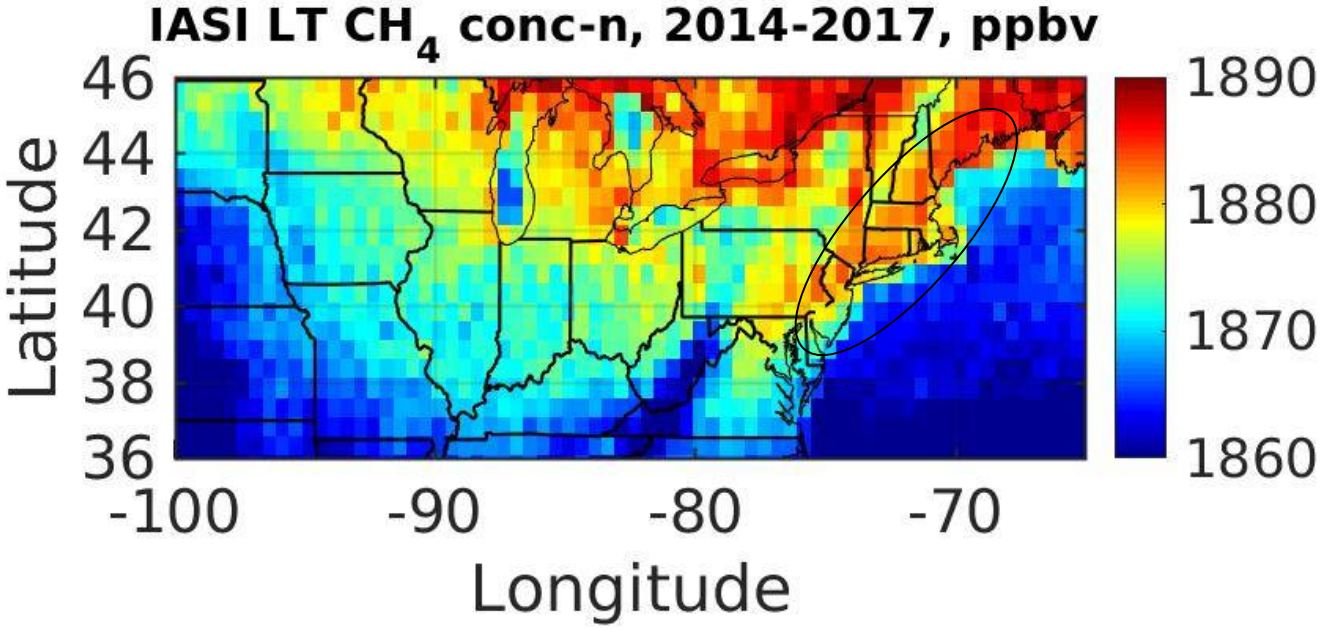
Example Three:

Anomaly of CH4 over USA

Low- and mid-upper tropospheric CH4 concentration over NE of USA

(color scales are different)





Annual means

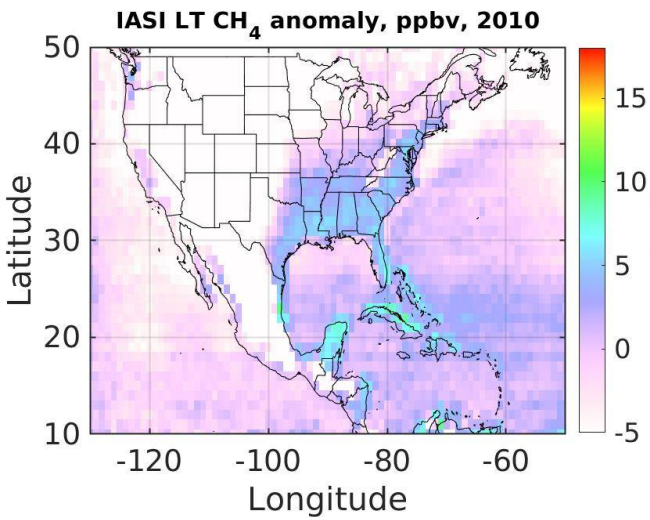
MUT

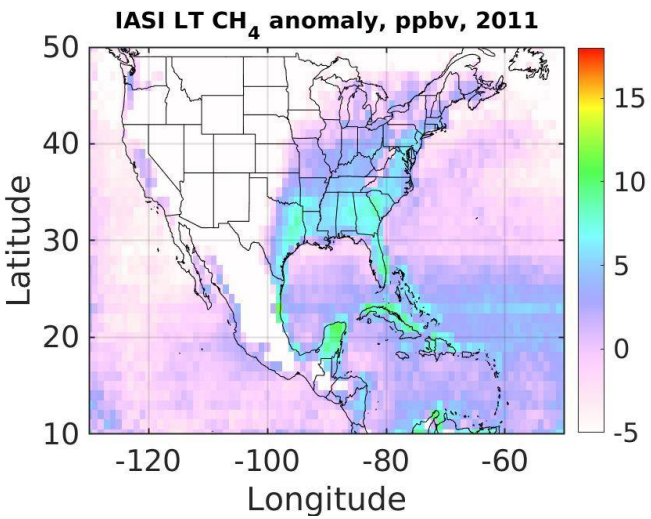
Latitudinal trend is significant,

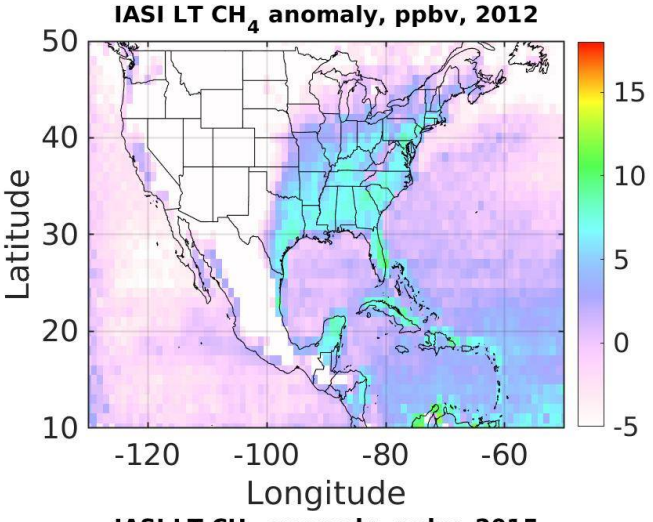
but **increased LT methane** over urbanized areas is observed

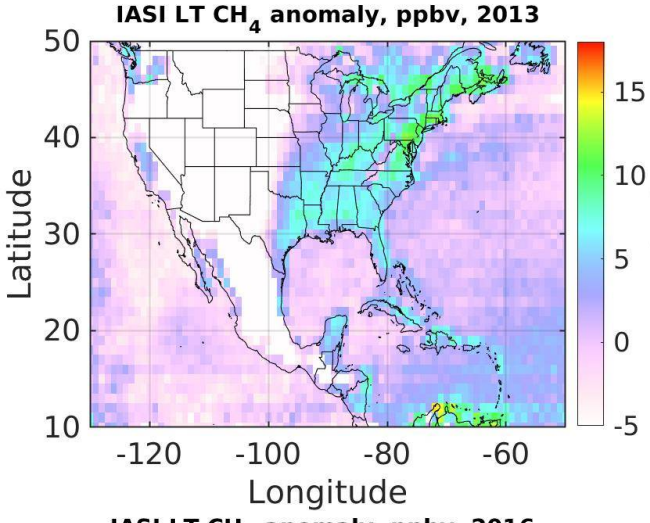
For anomaly it is more clear (next slide)

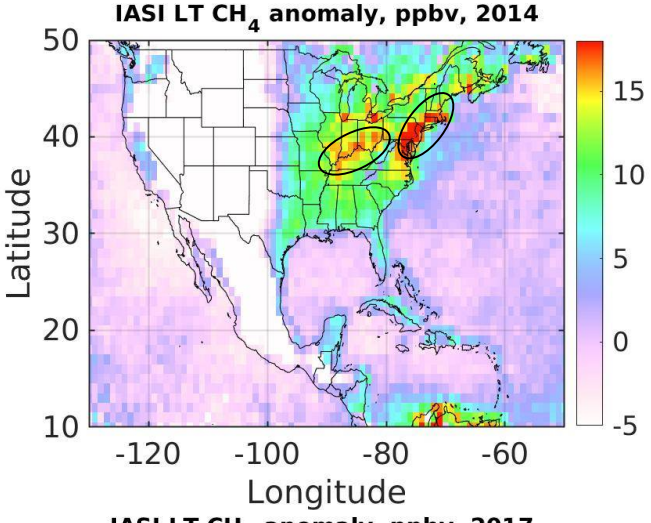
LT

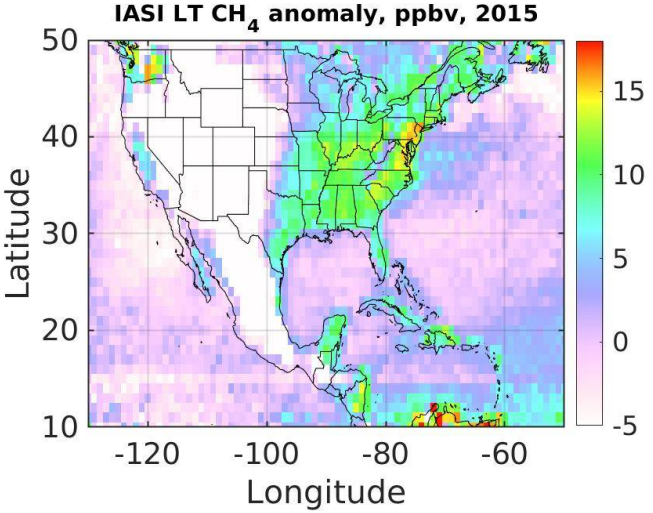


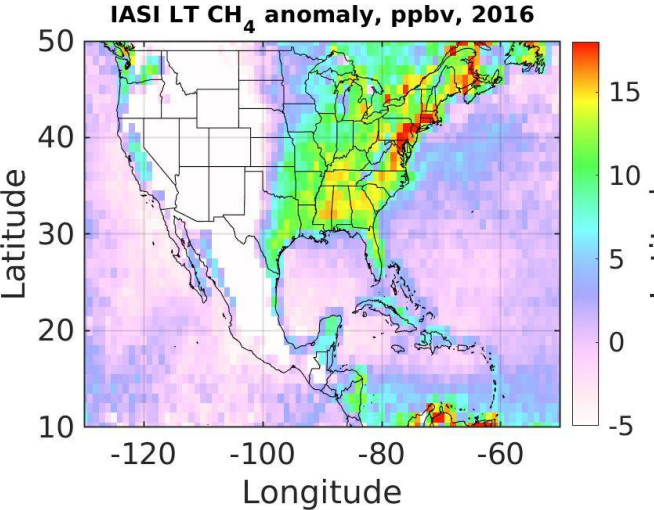


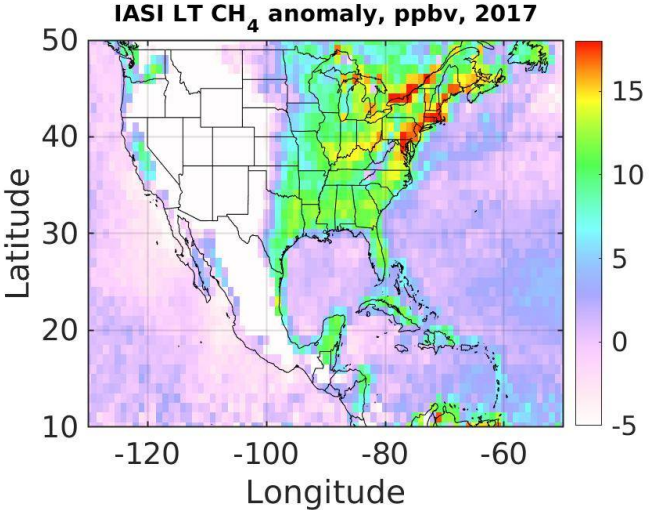








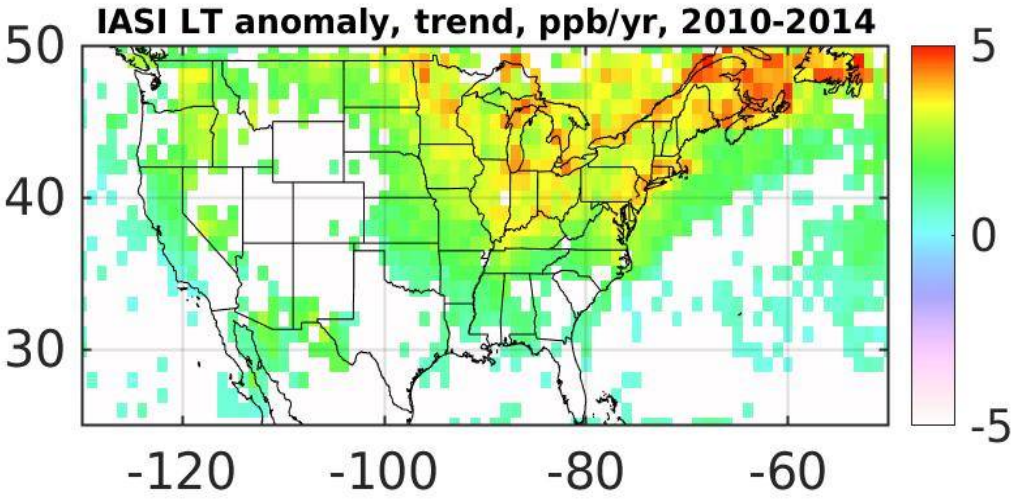




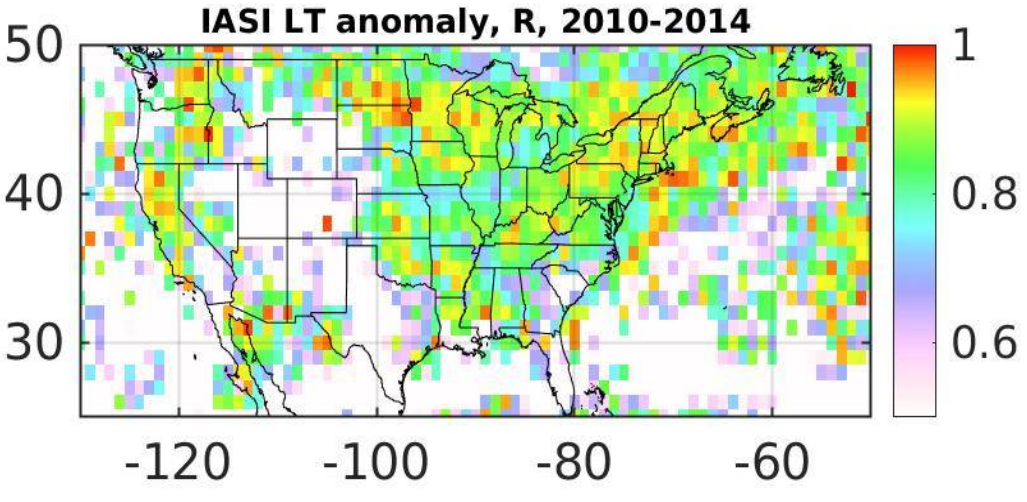
<u>Low tropospheric methane</u>
annual mean anomaly,
calculated as a surplus over Pacific background. increased from 2010 to 2017. Note the areas with maximal anomalies: DC – NYC corridor, Ohio river, Toronto-Montreal corridor.
(color scales are the same)

Comparison with GOSAT data

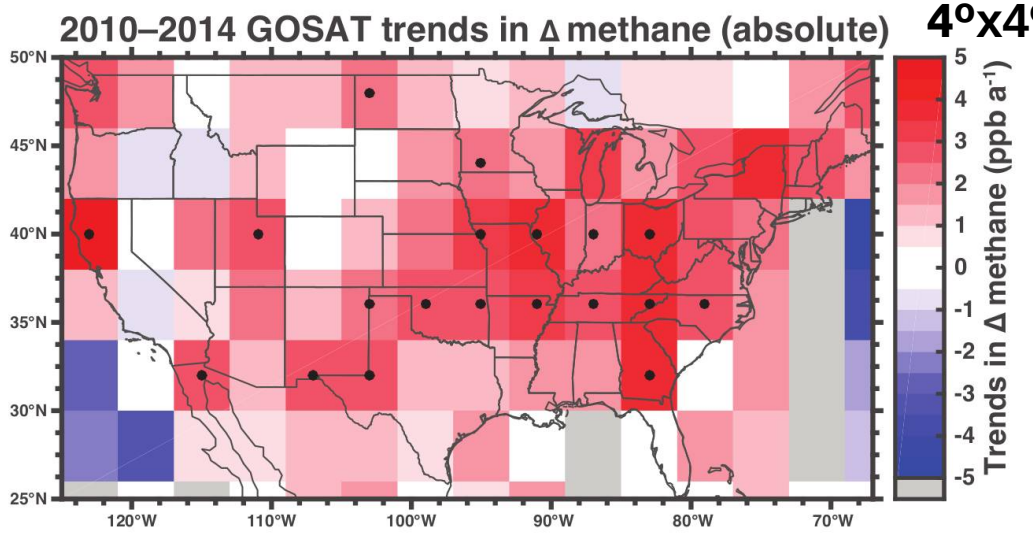
IASI trend (slope), 1ºx1º



IASI corr. coefficient



4ºx4º



IASI LT data correlate with total column data of a SWIR interferometer GOSAT/TANSO. In both cases statistically significant slopes of linear regression lines are in the range **2-4 ppb/yr** for a period between 2010 and 2014

Color scales are the same

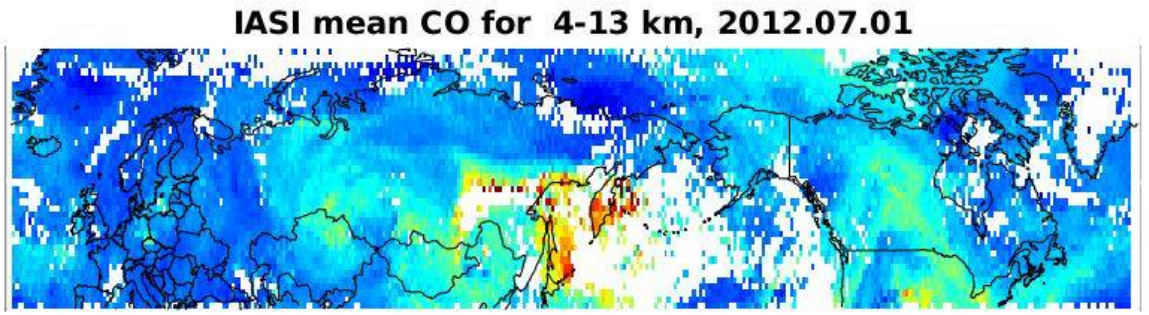
Supporting material for "***A large increase in US methane emissions over the past decade inferred from satellite data and surface observations***" **by A. J. Turner et al.**, Geophys. Res. Lett., 43, 2218–2224

10/03/18

Example Four: Siberian wildfires

Lower and mid-upper tropospheric CO from Siberian wildfires in 2012

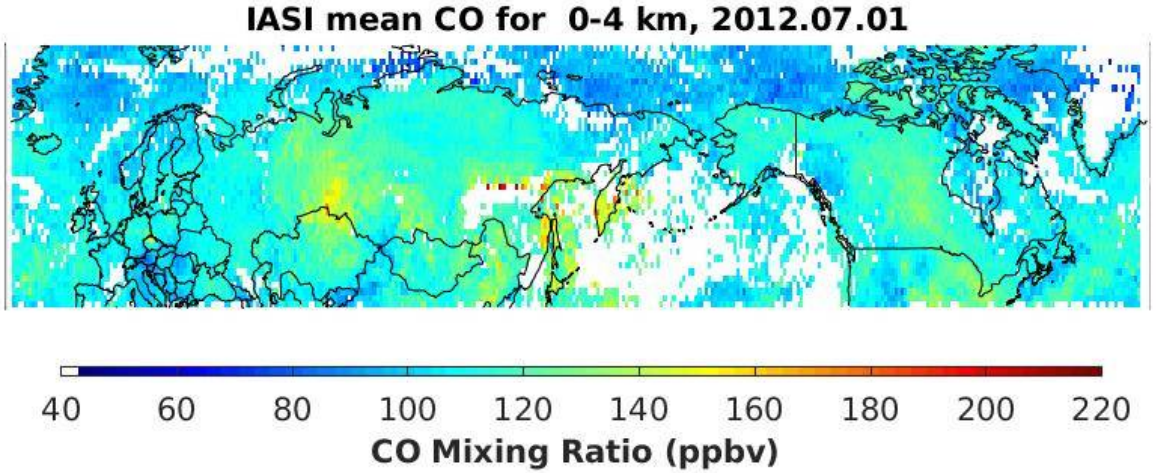
(do not confuse with Moscow fires of 2010)



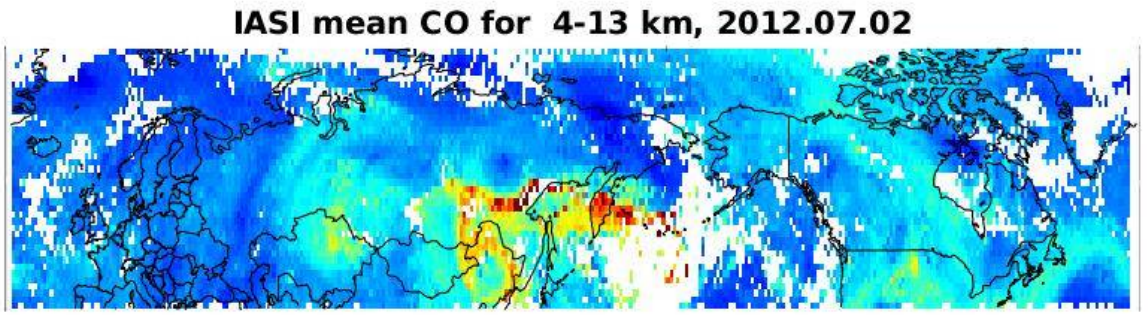
Daily IASI CO

For upper troposphere:

Color scales are the same



For lower troposphere:



Daily IASI CO

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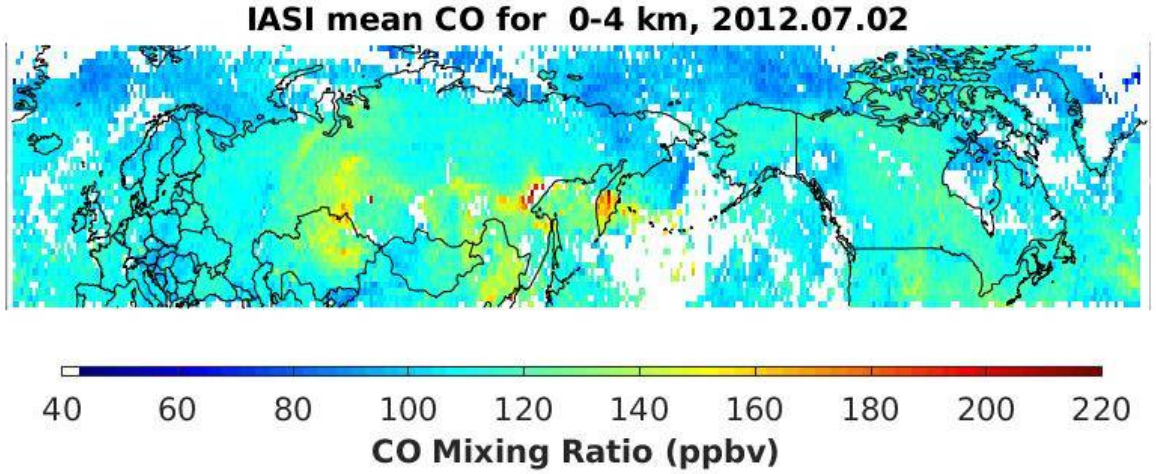
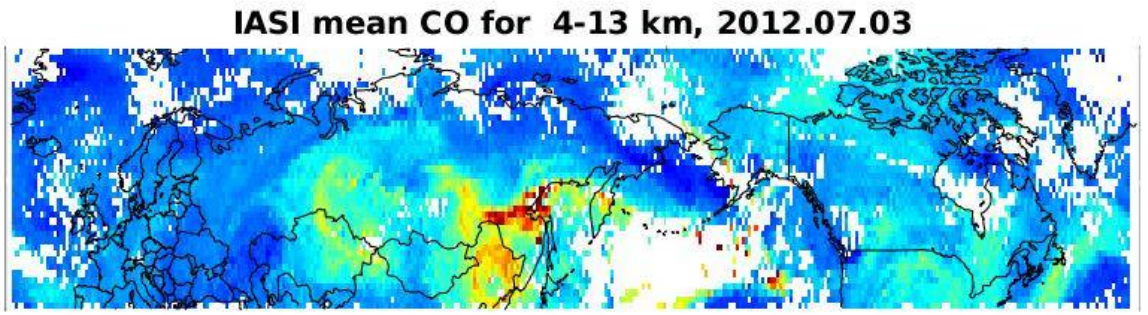


For lower troposphere:



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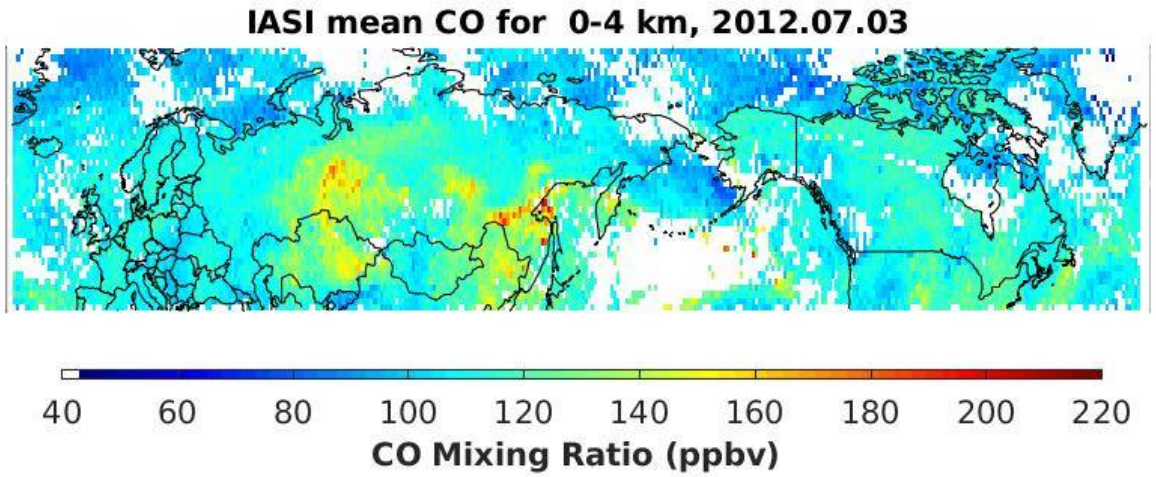

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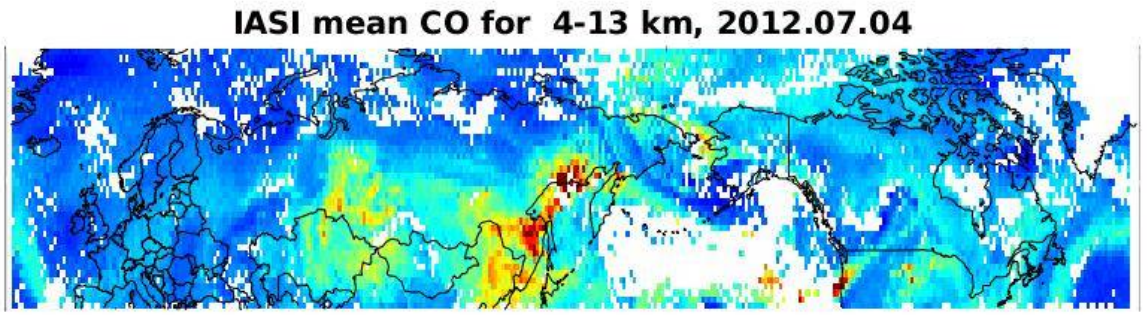

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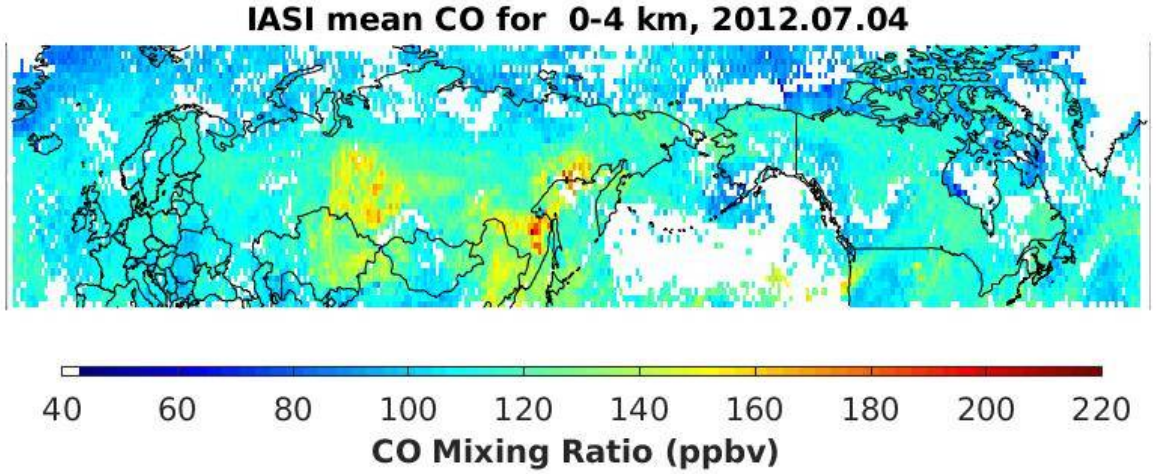

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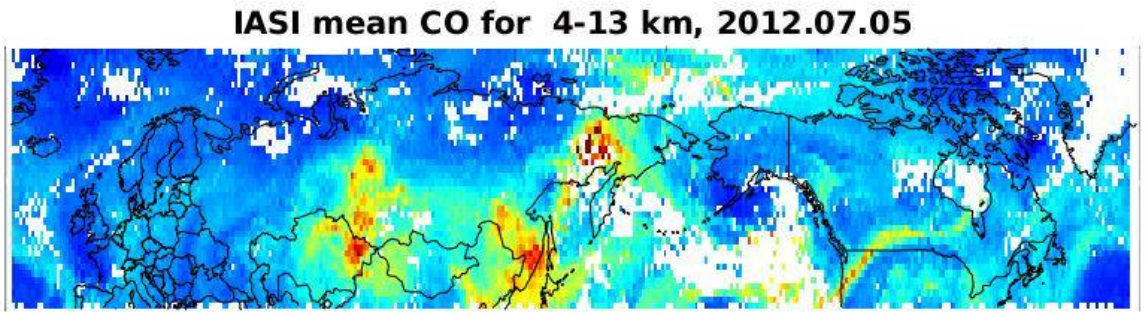

Daily IASI CO

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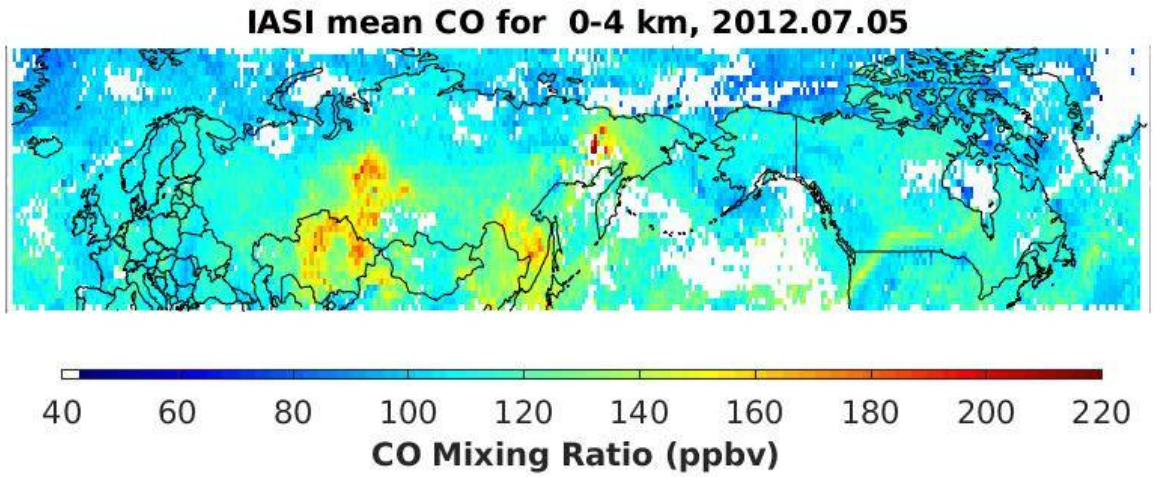

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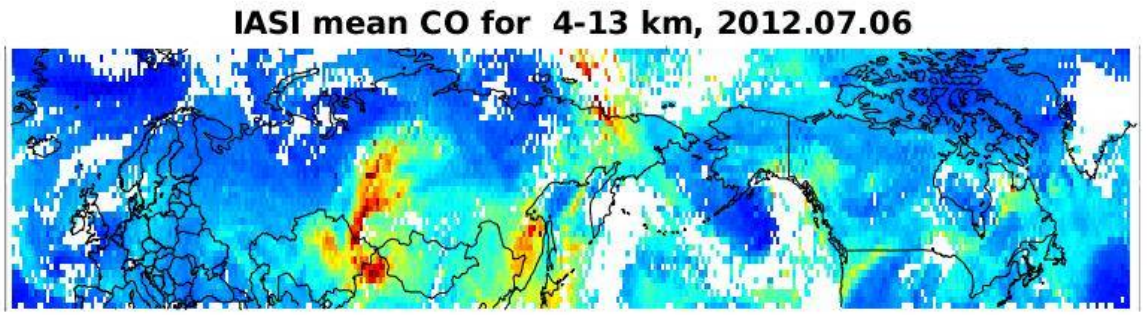

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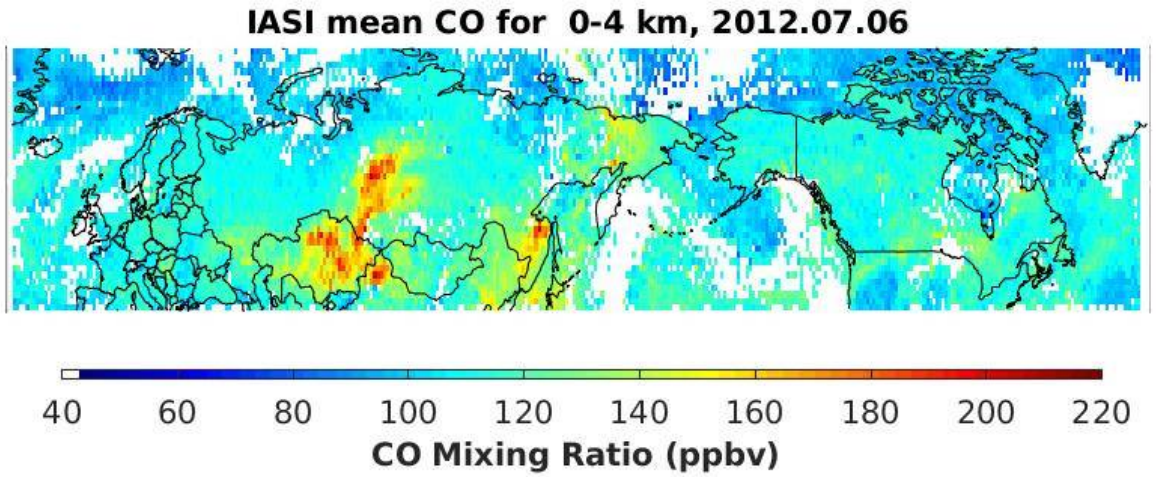

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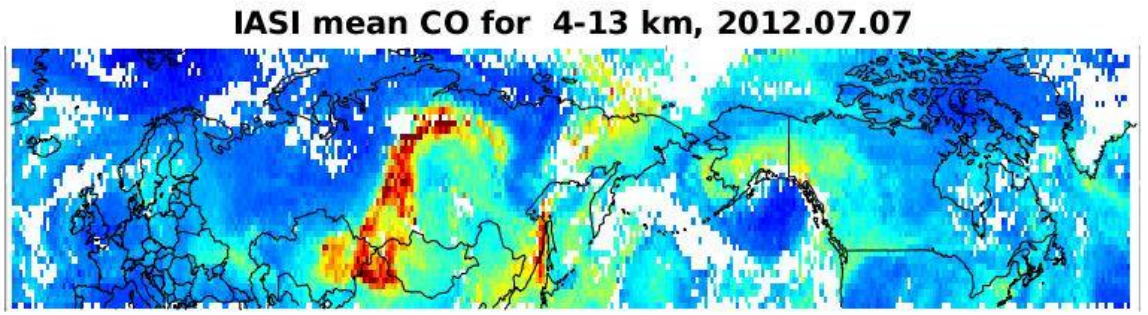

Daily IASI CO

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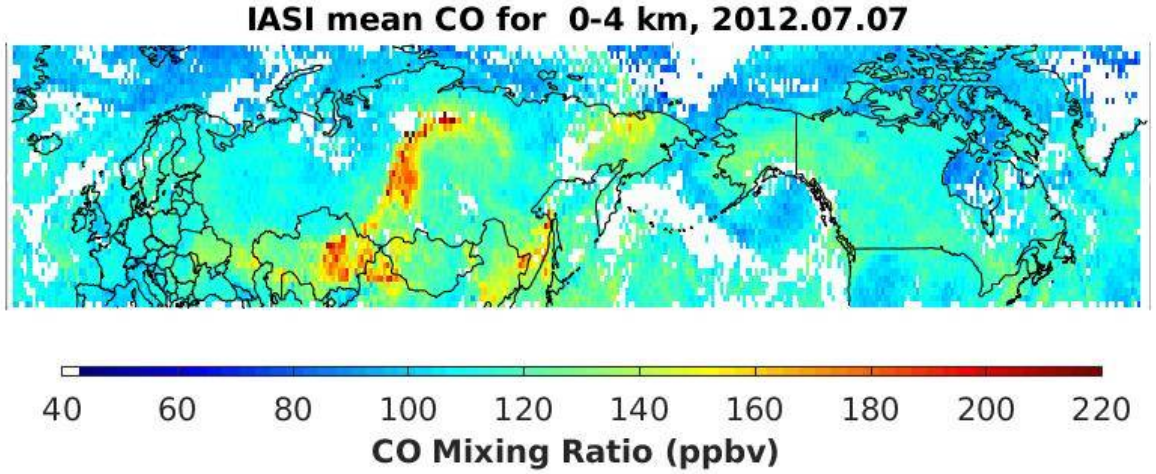

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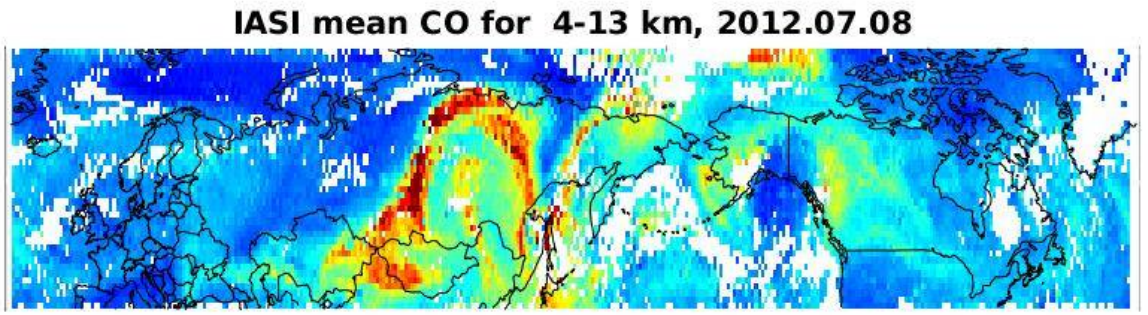

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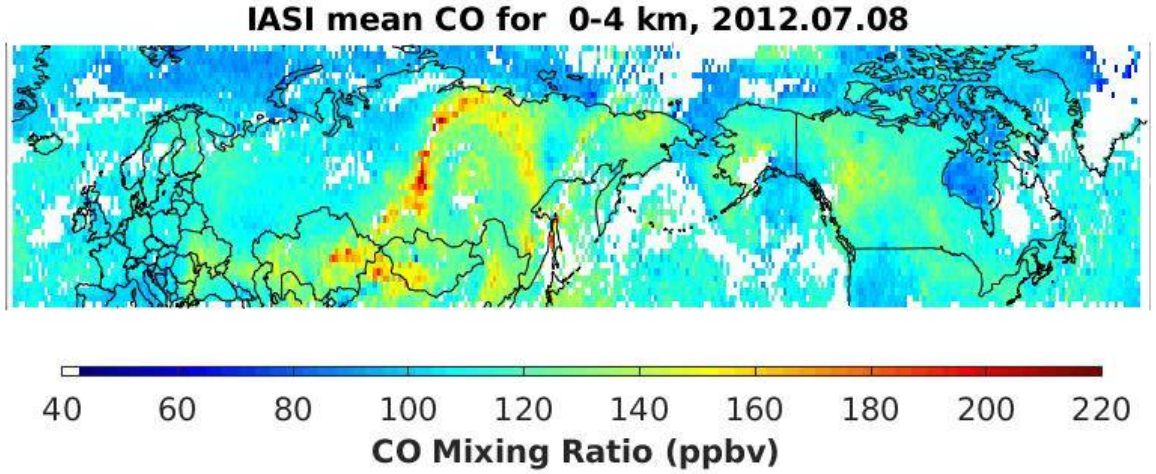

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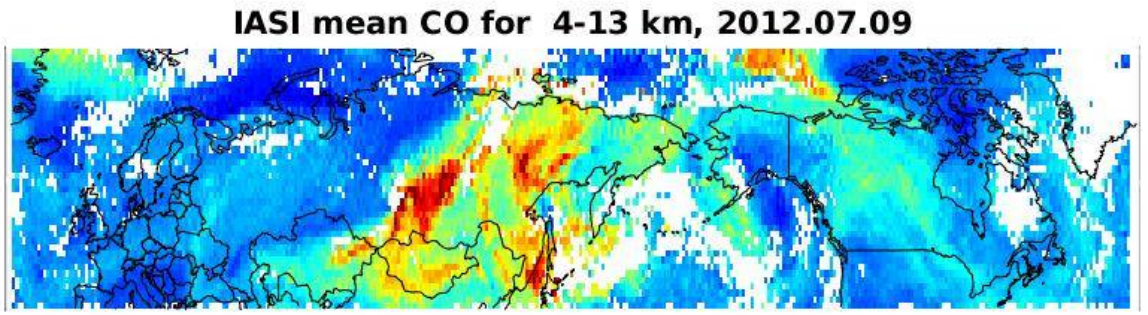

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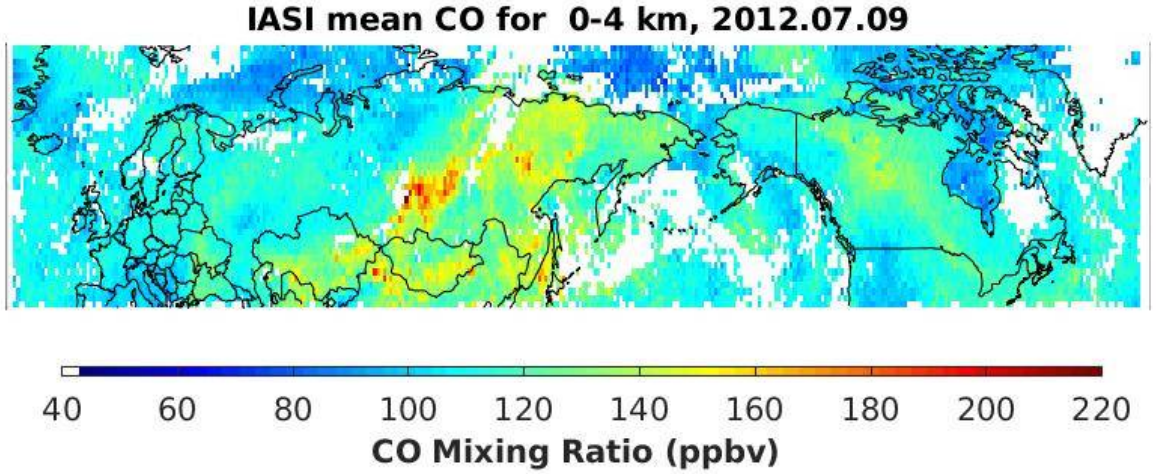
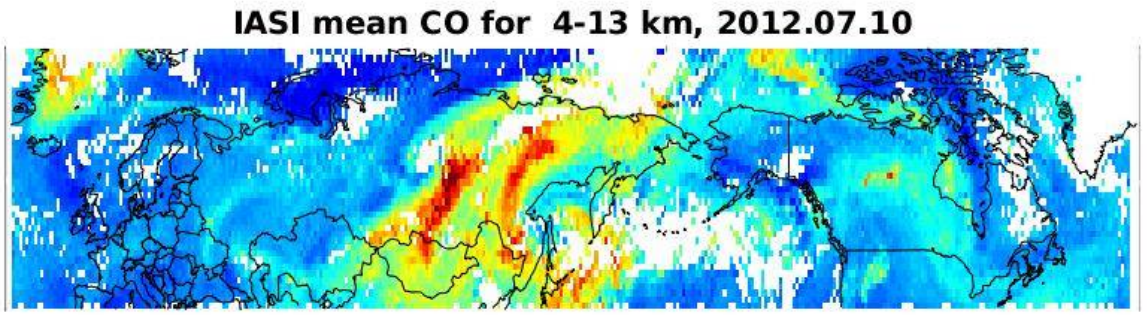


For lower troposphere:



Daily IASI CO

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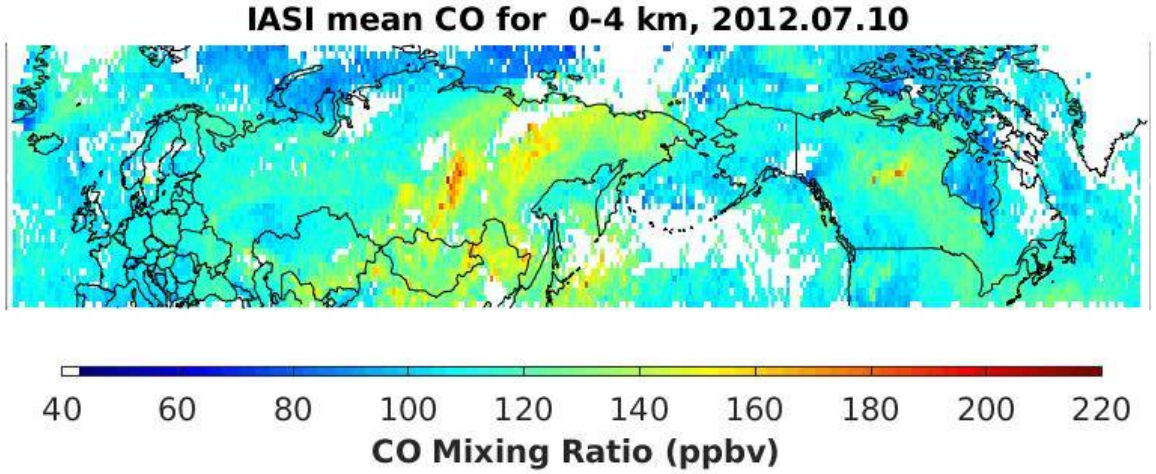

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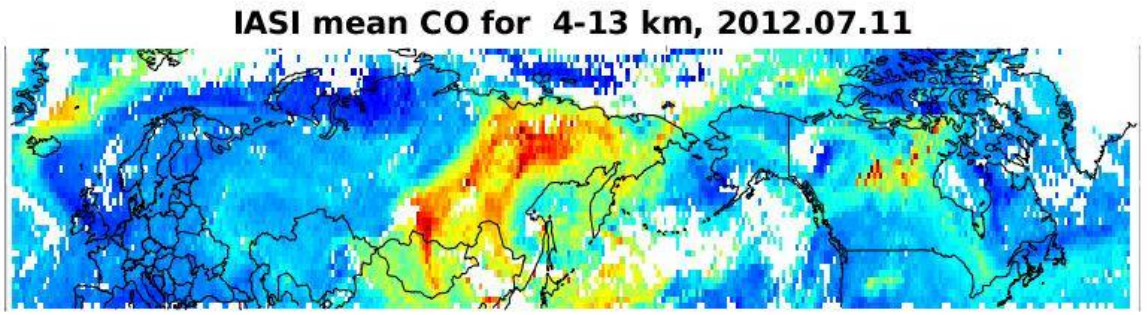

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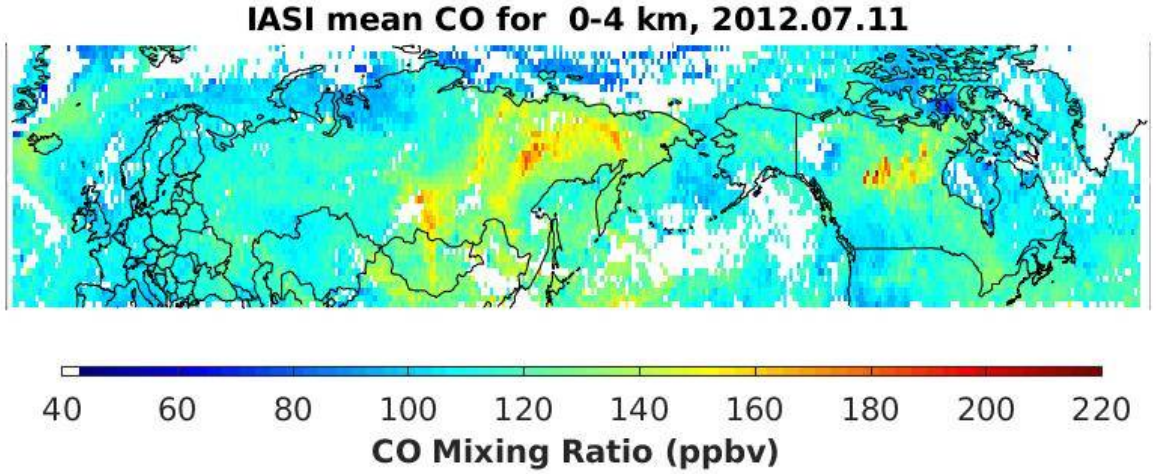

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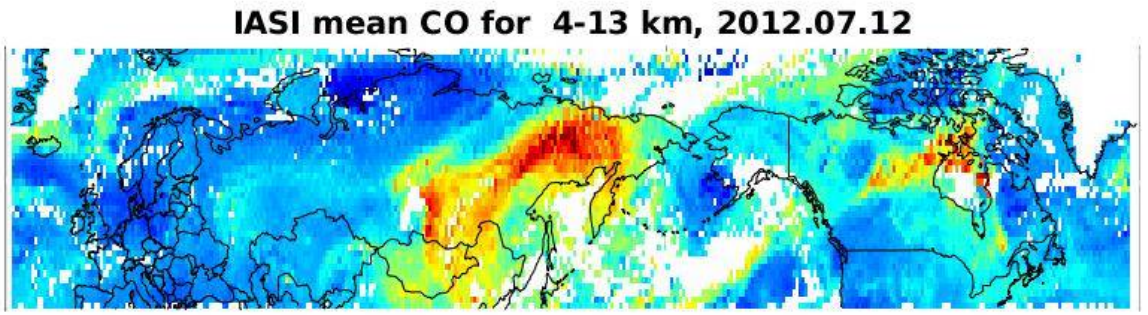

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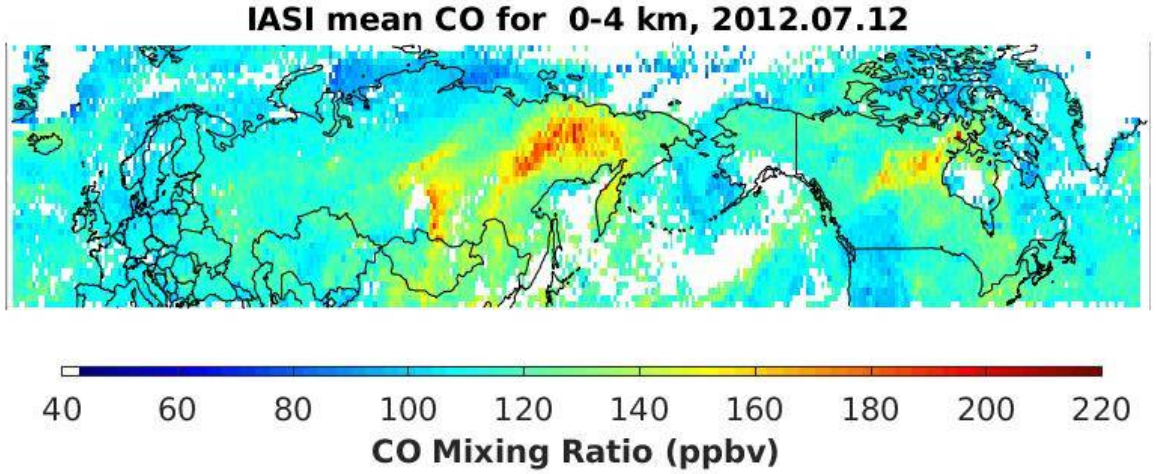

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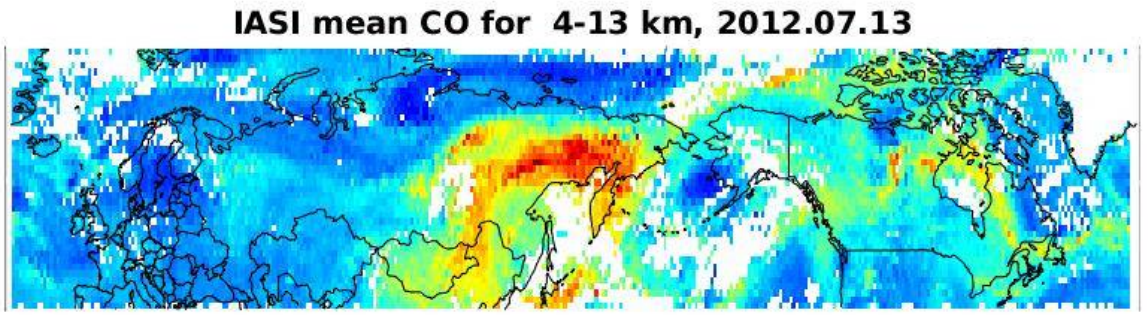

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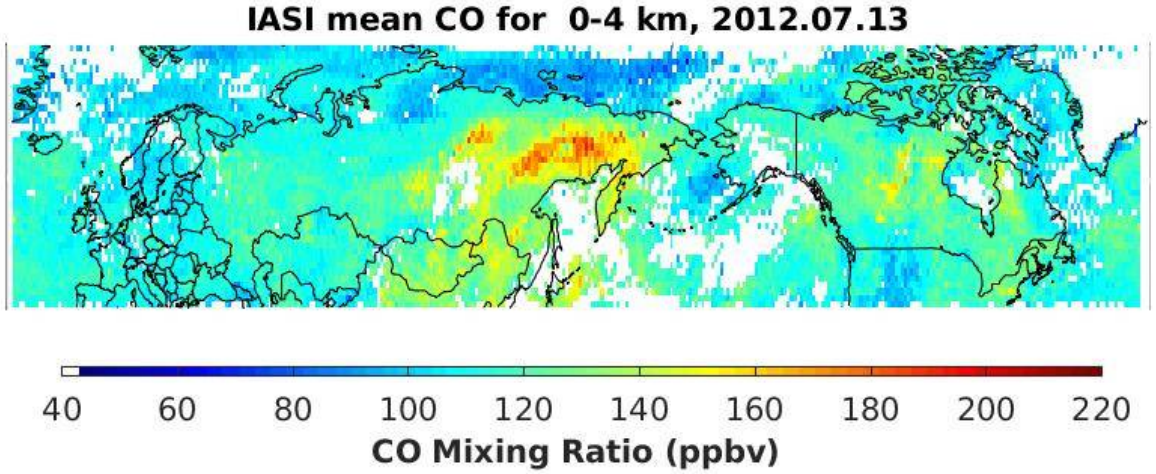

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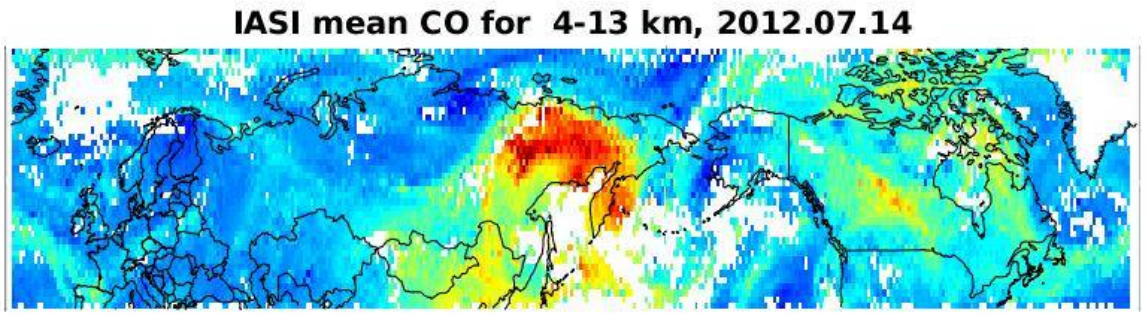

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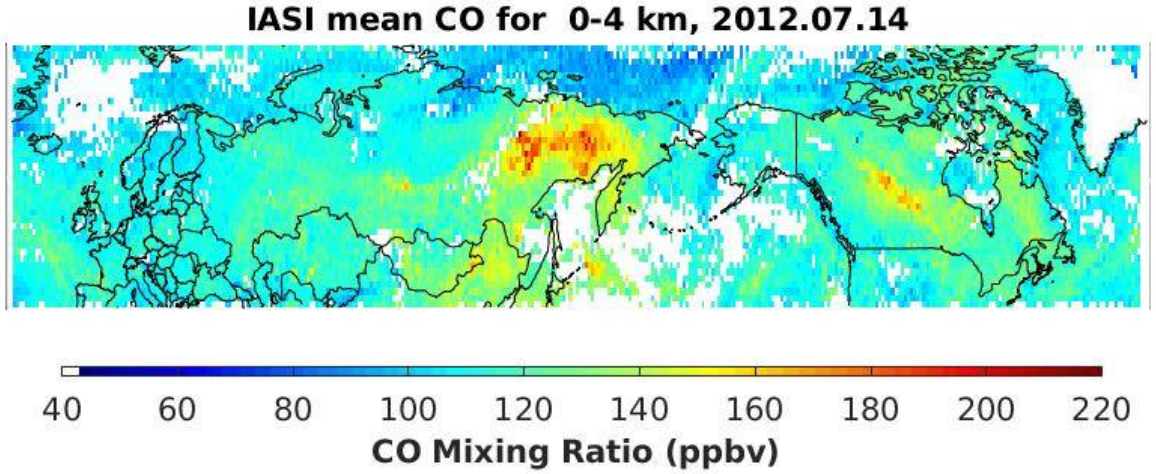

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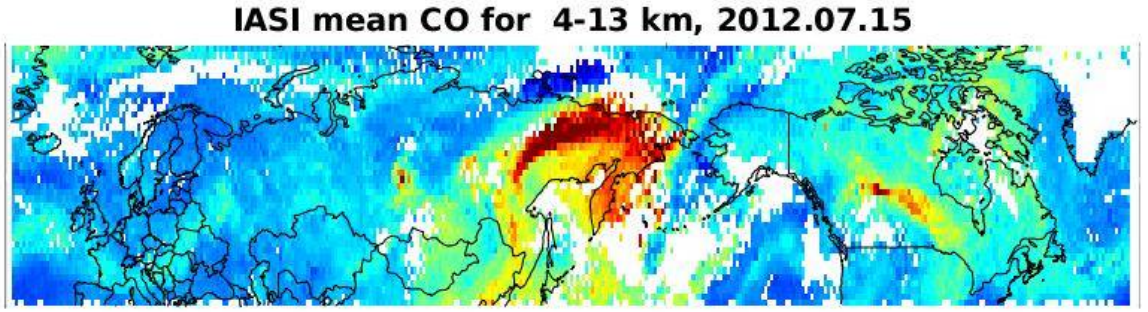

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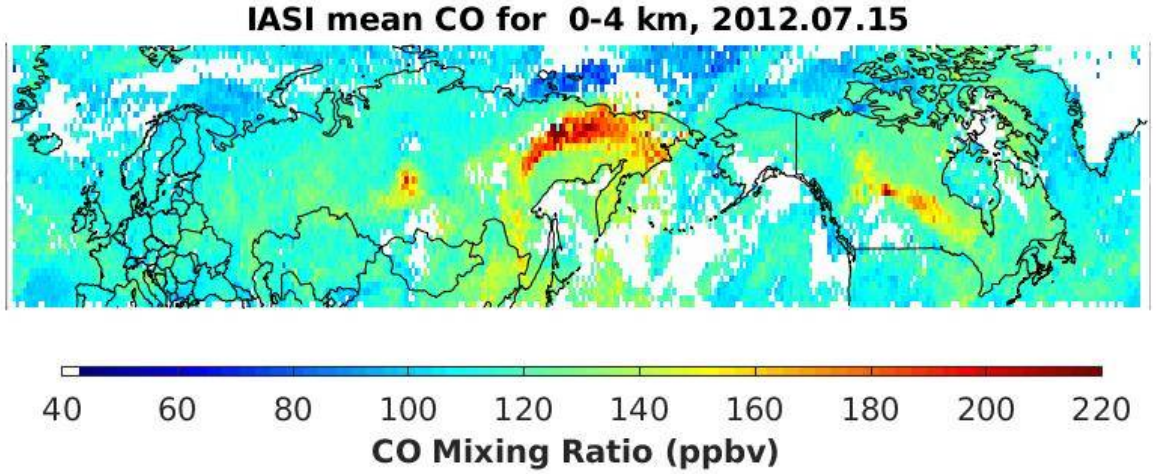

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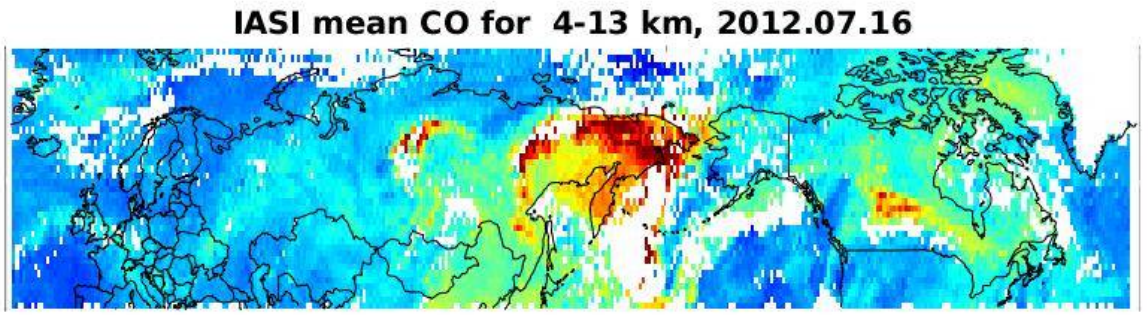

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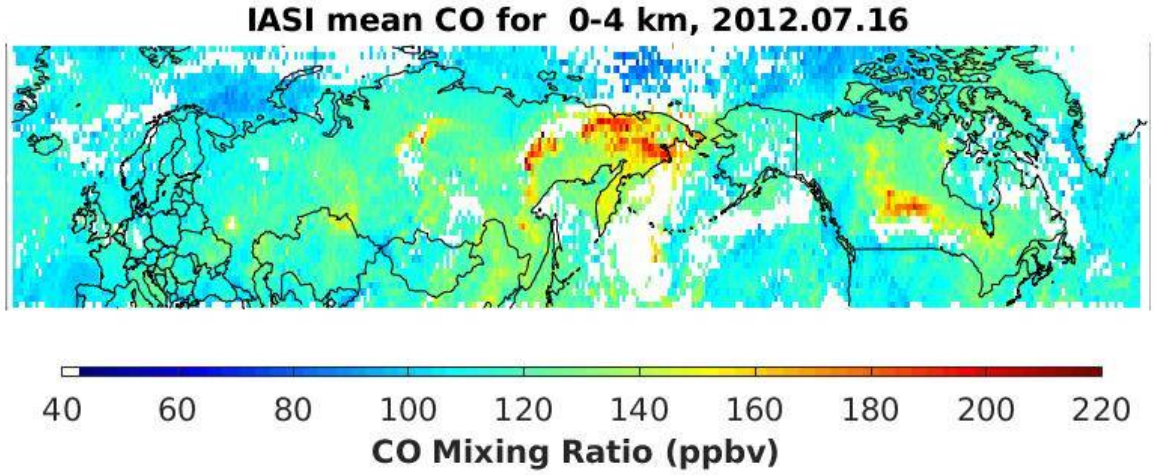

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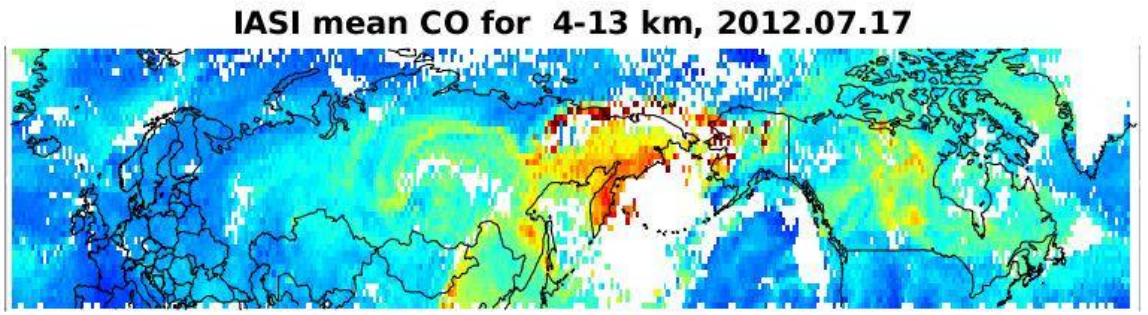

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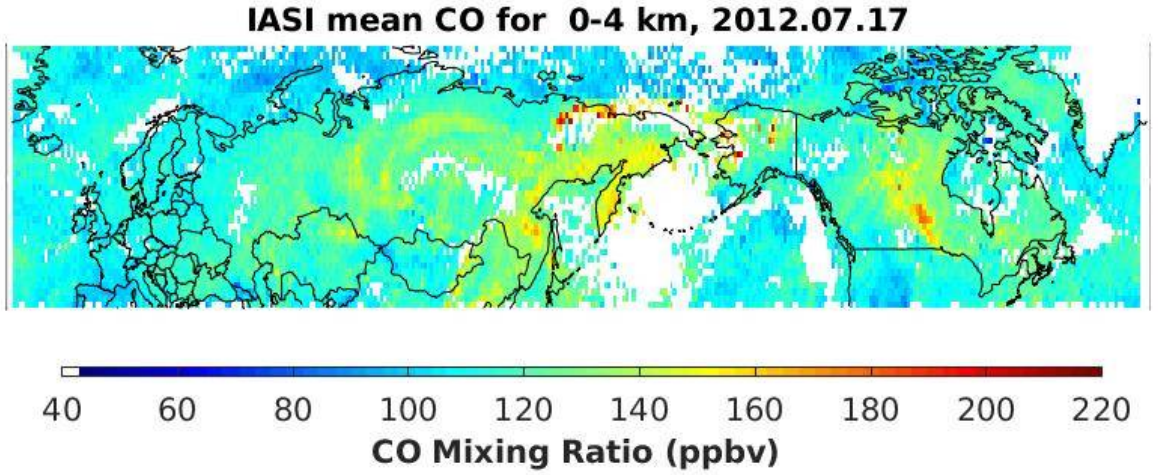

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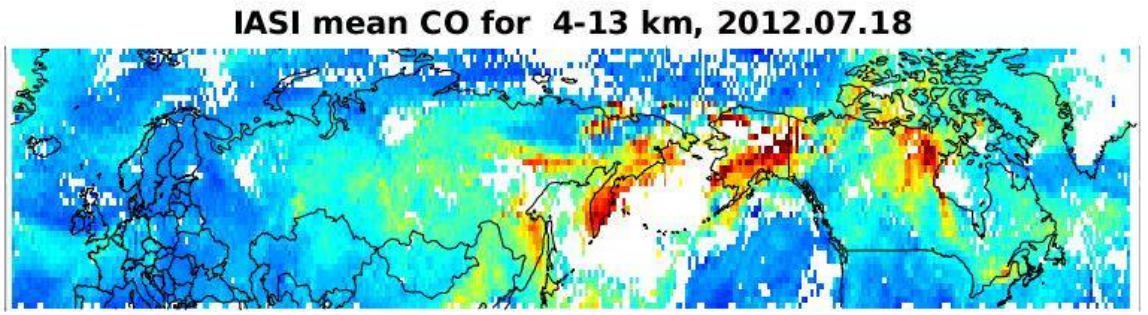

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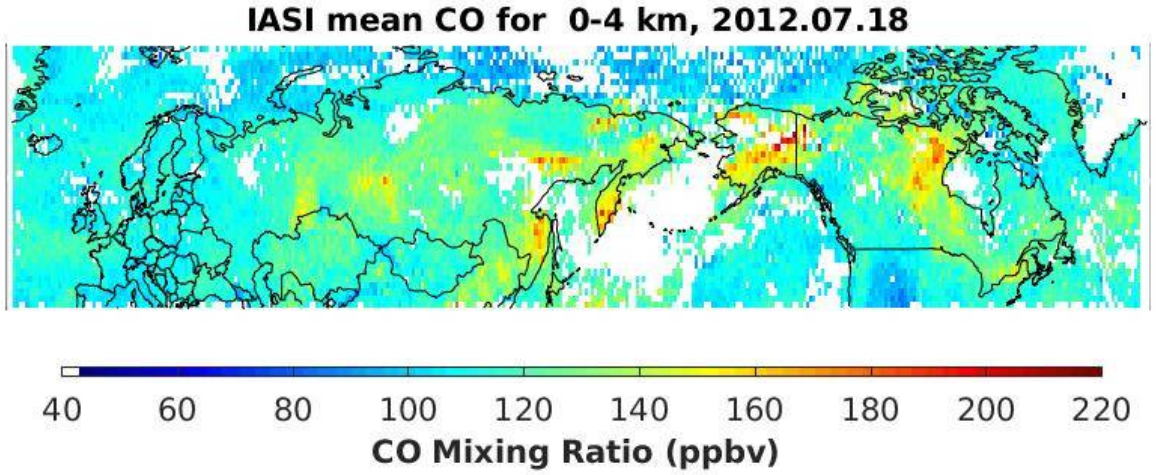

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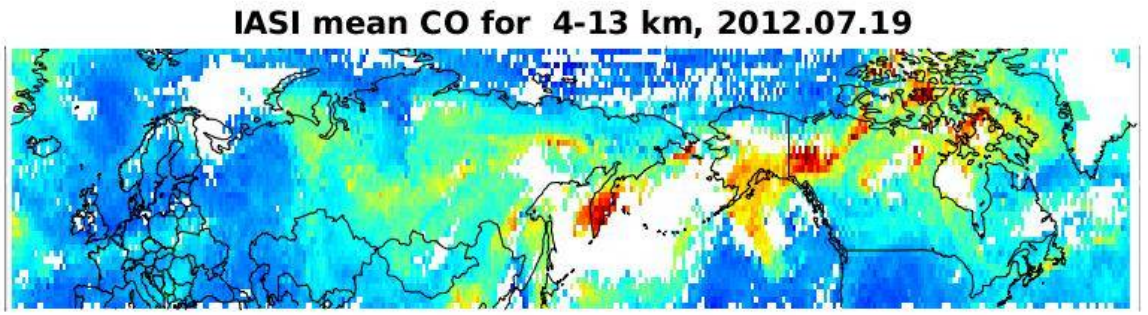

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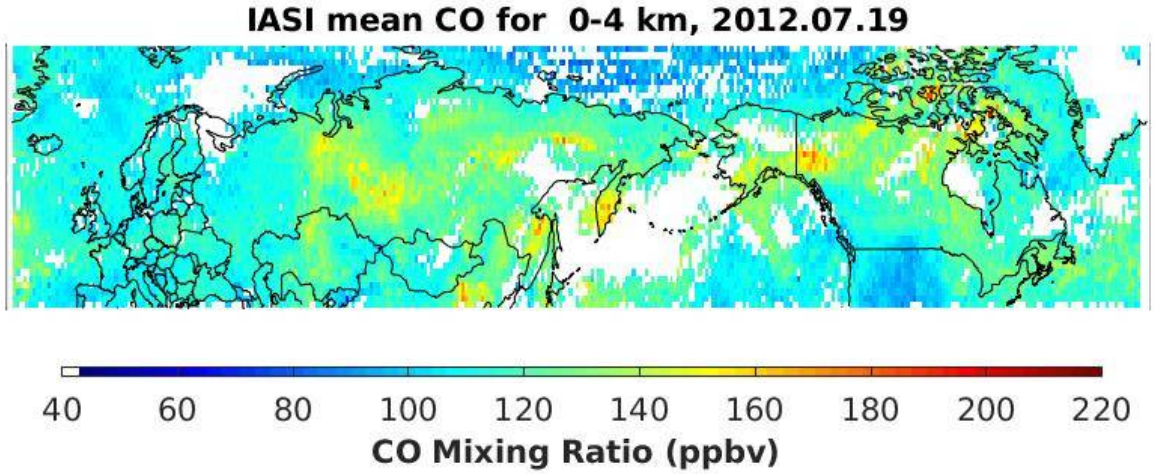

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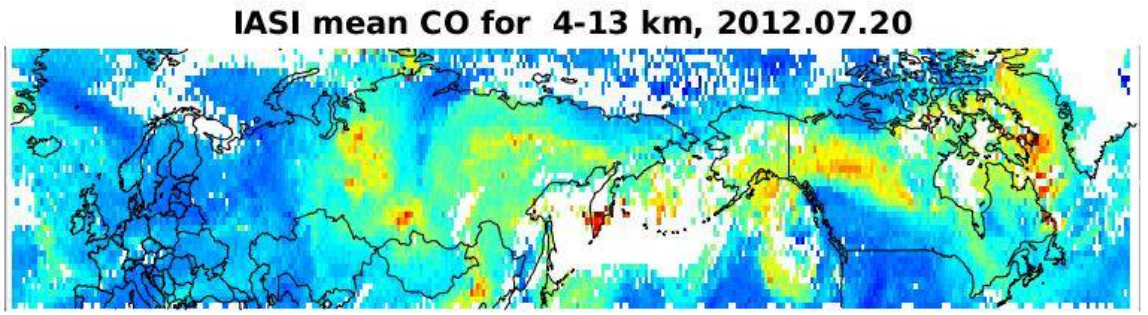

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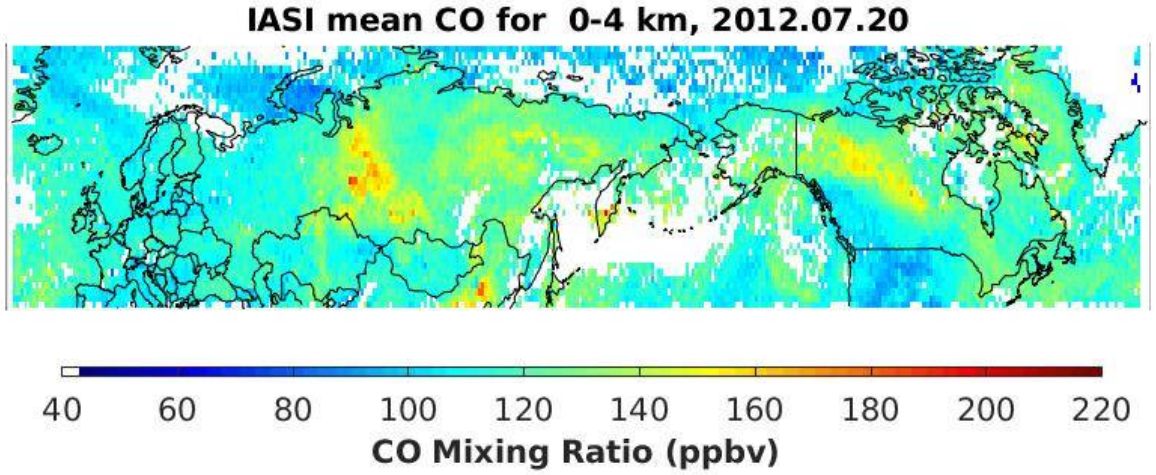

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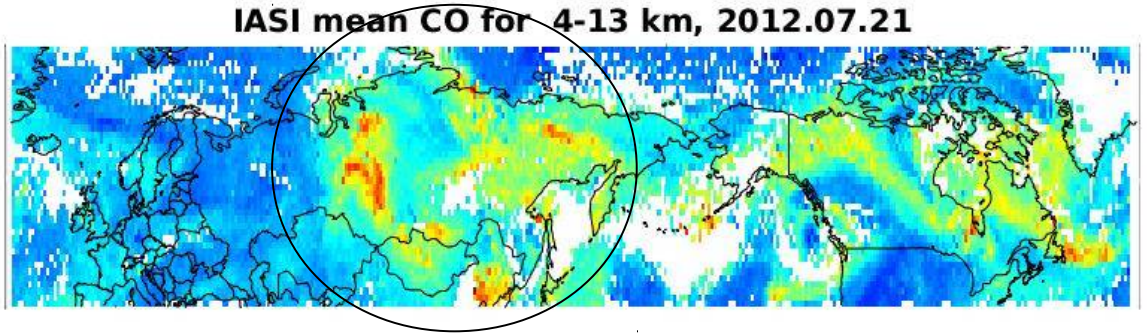

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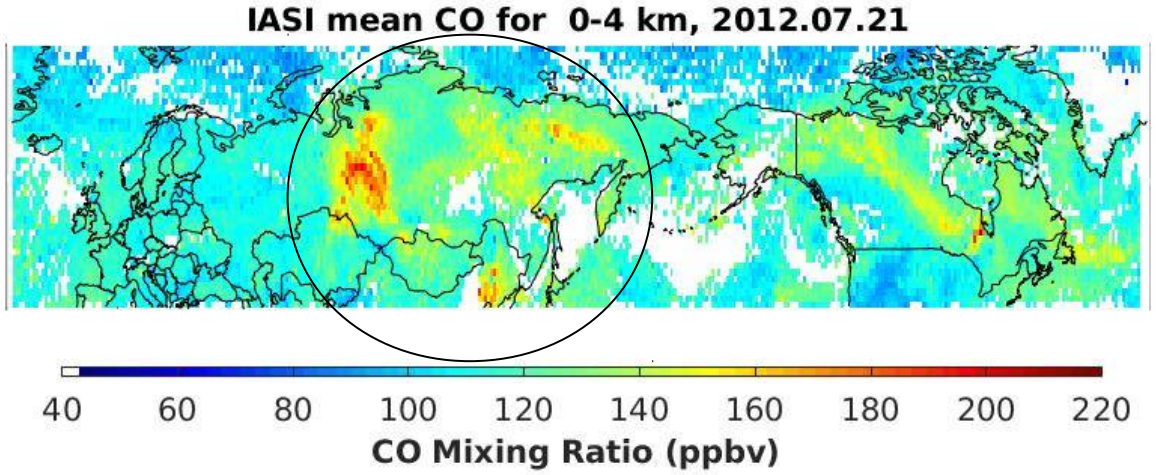

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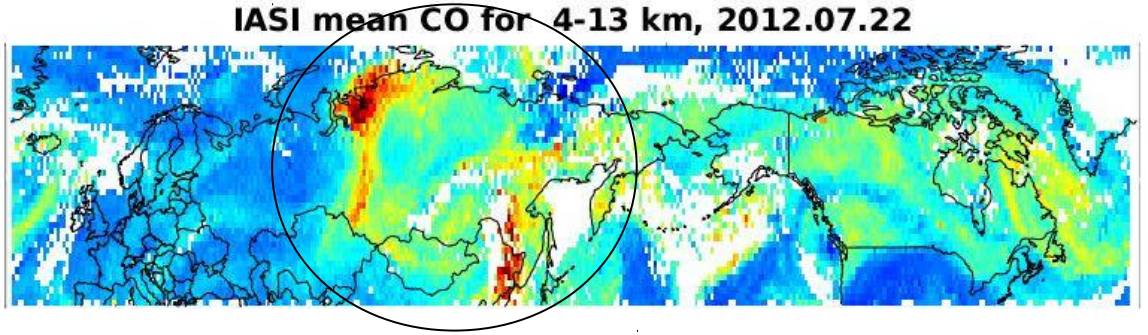

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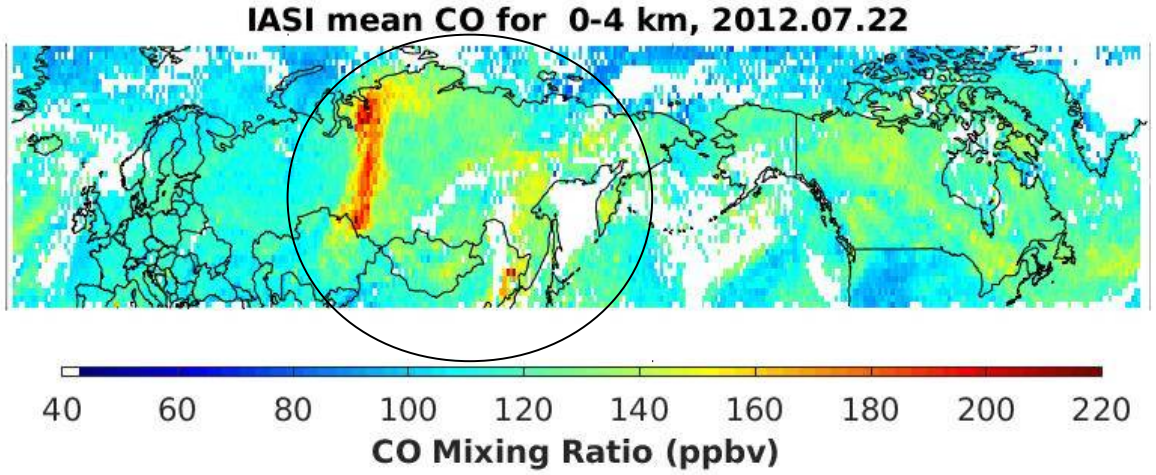

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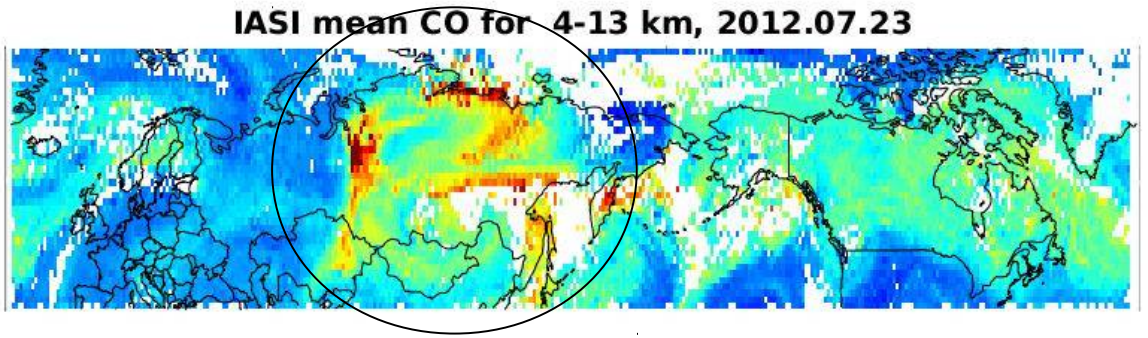

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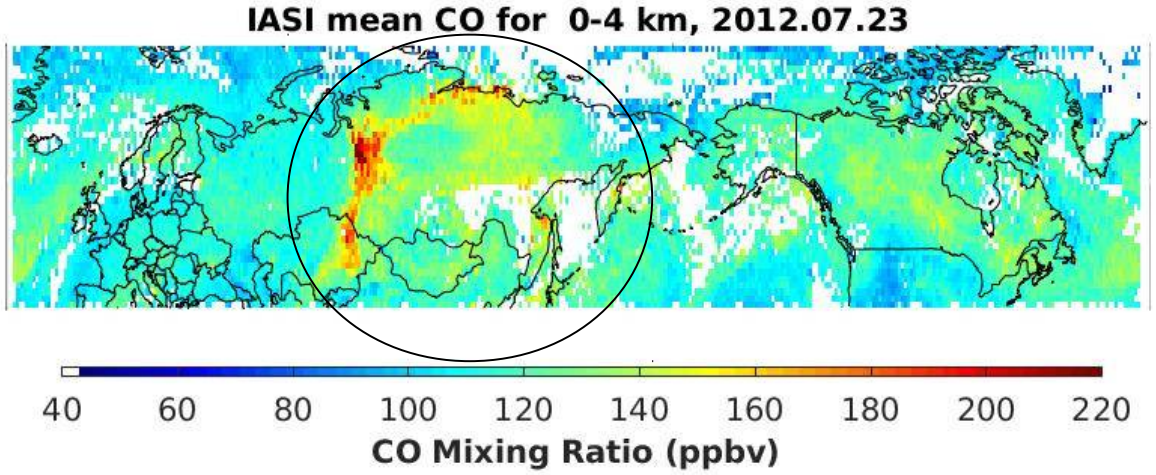

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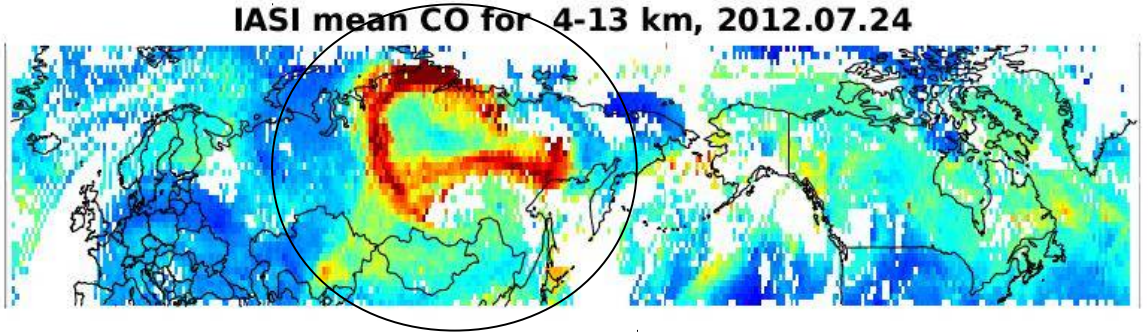

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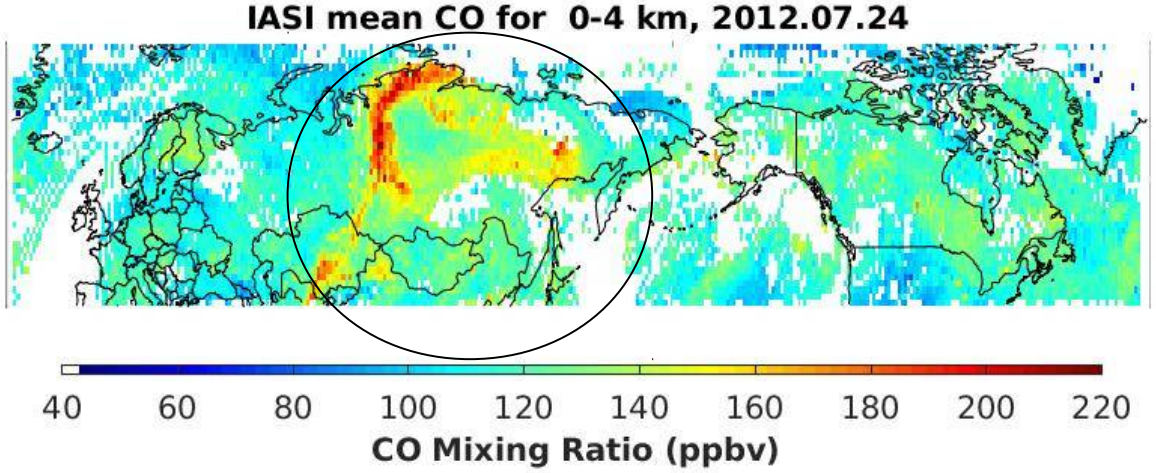

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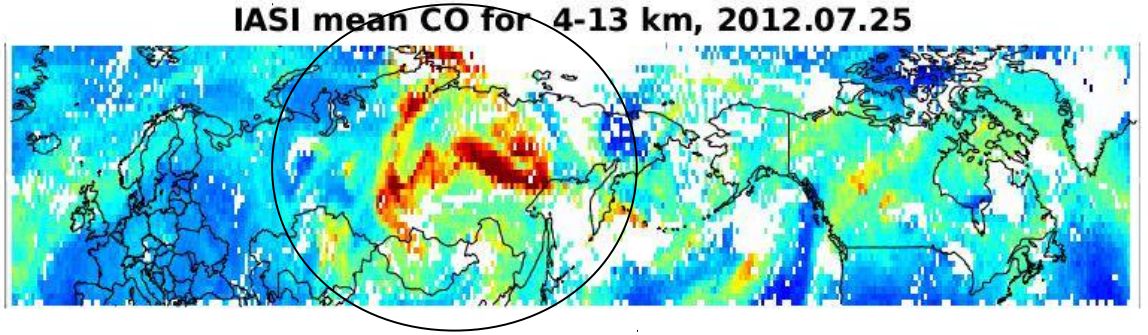

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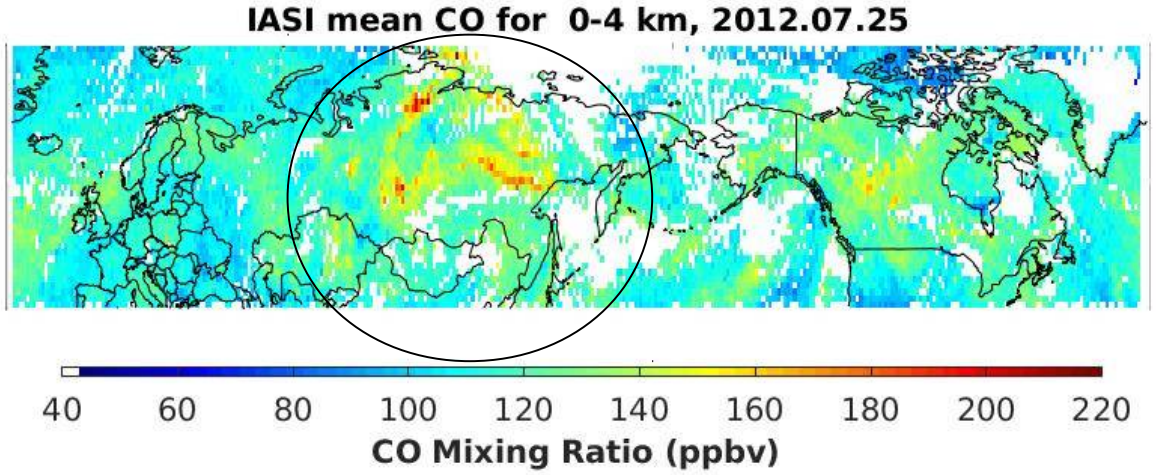

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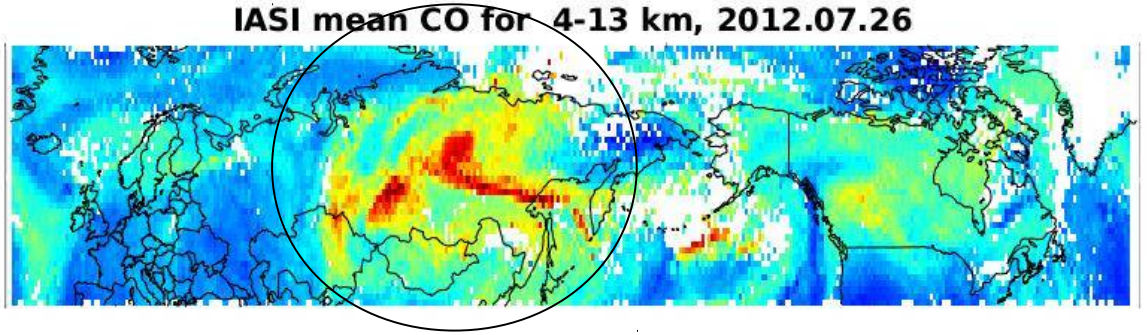

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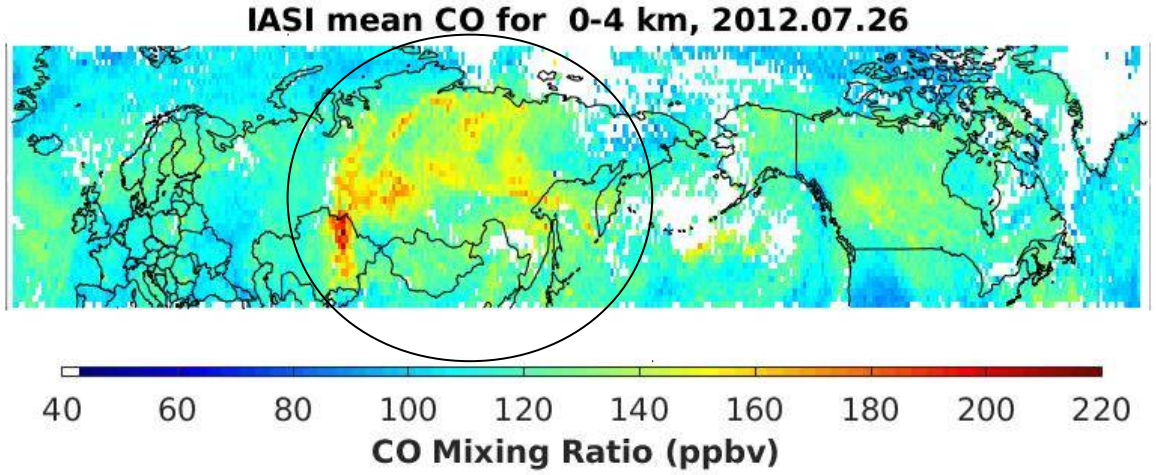

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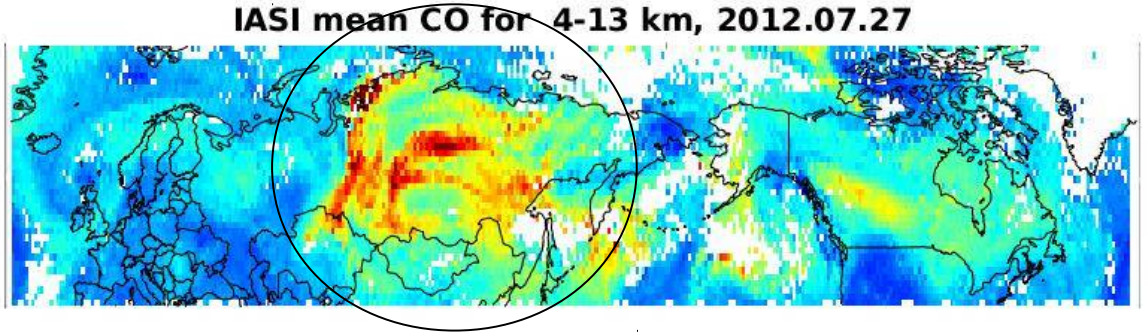

Daily IASI CO

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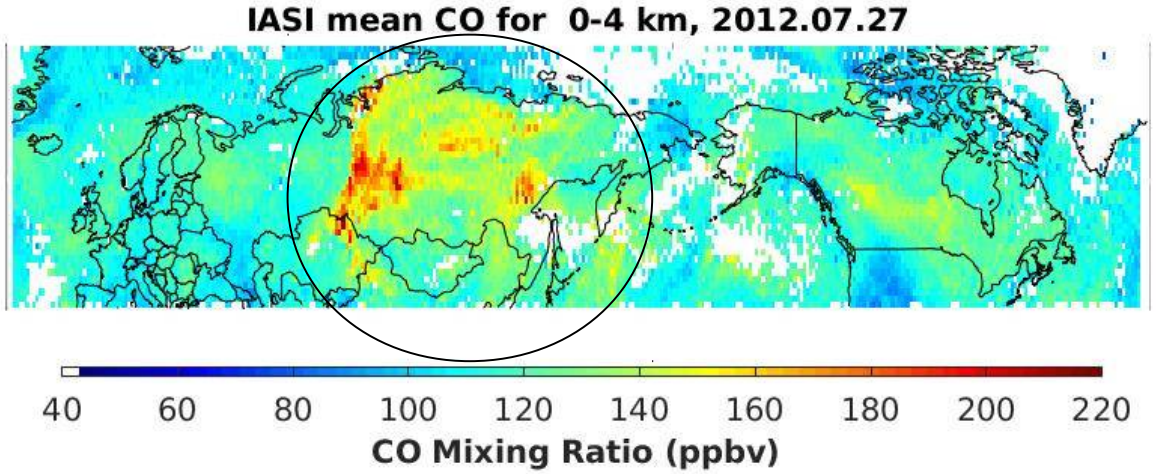

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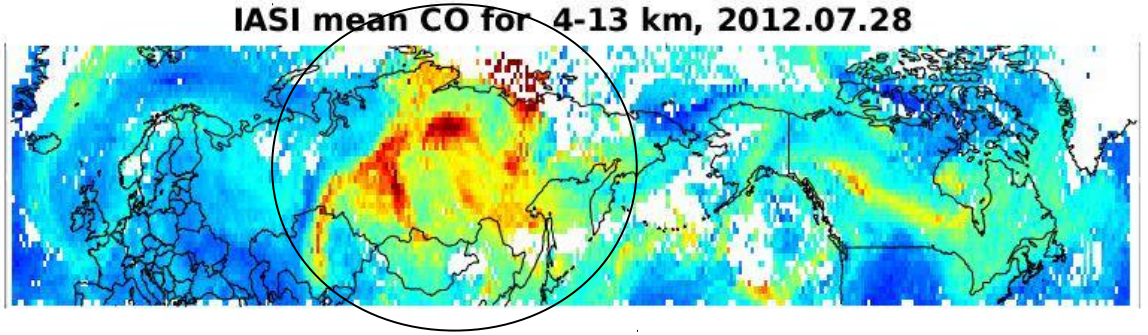

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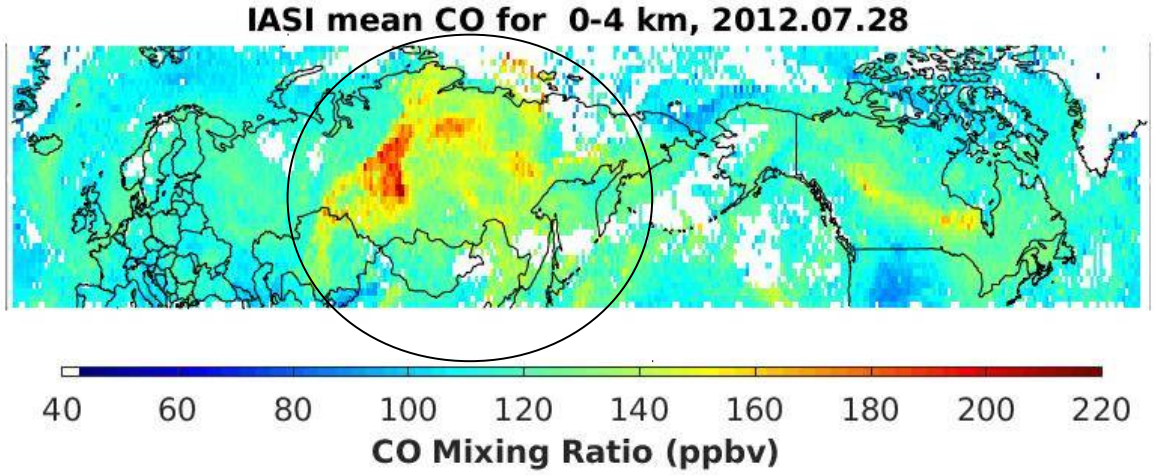

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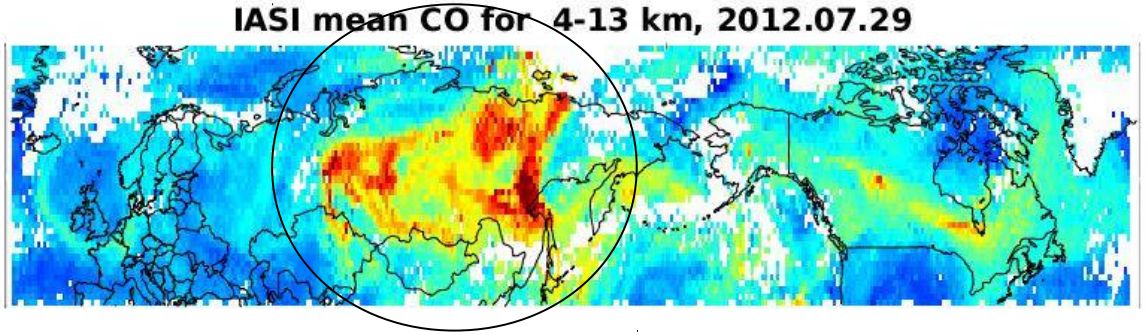

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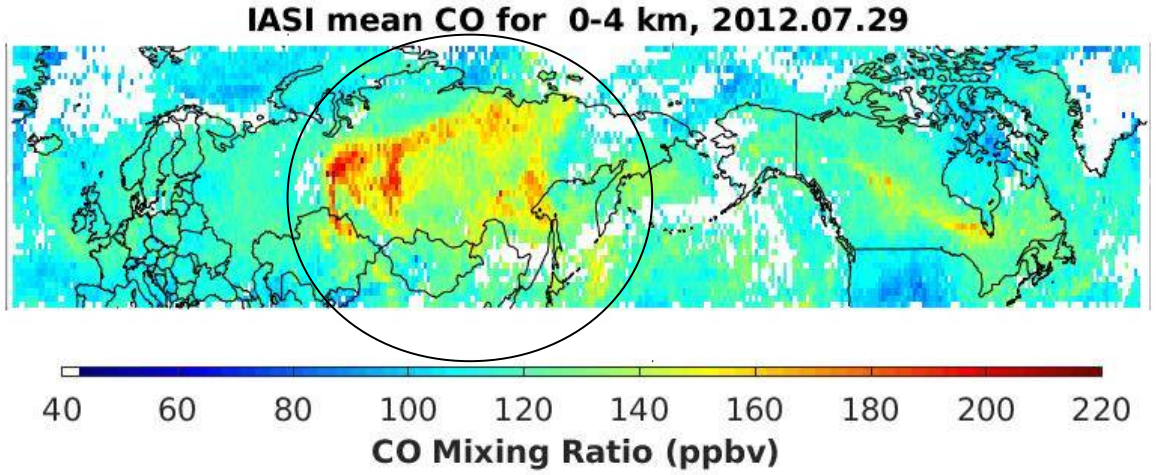

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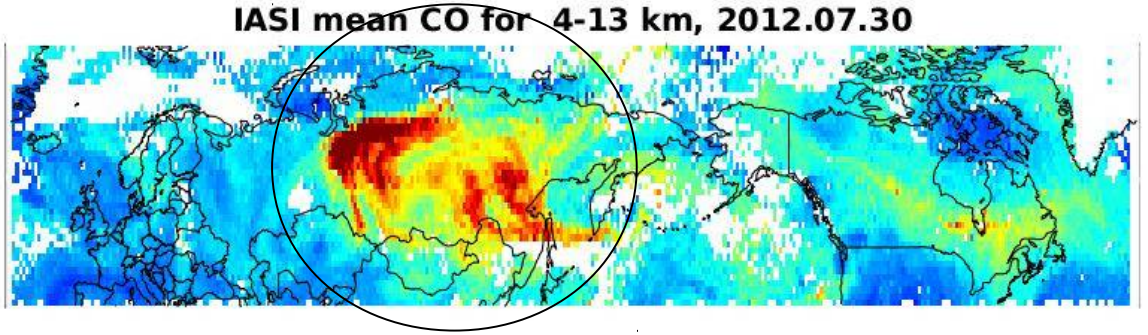

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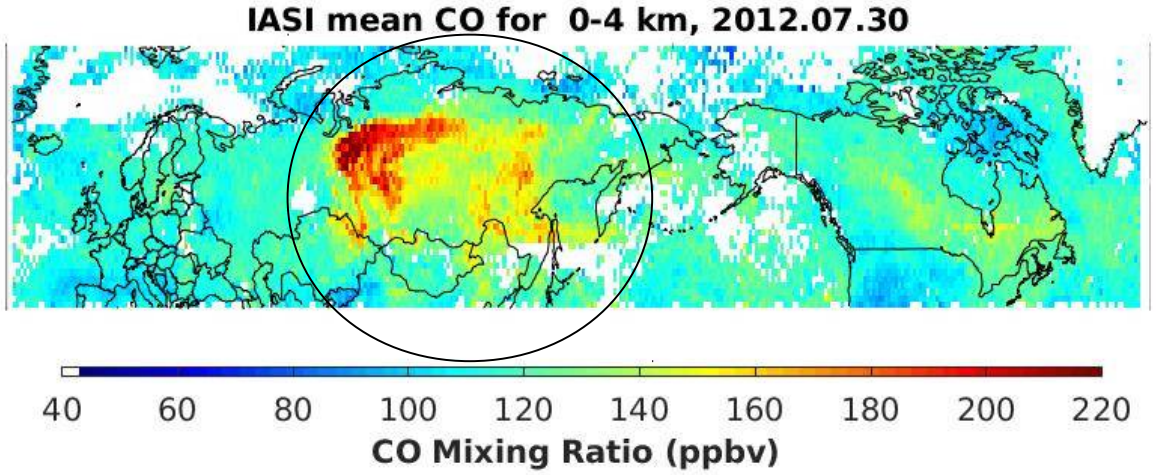

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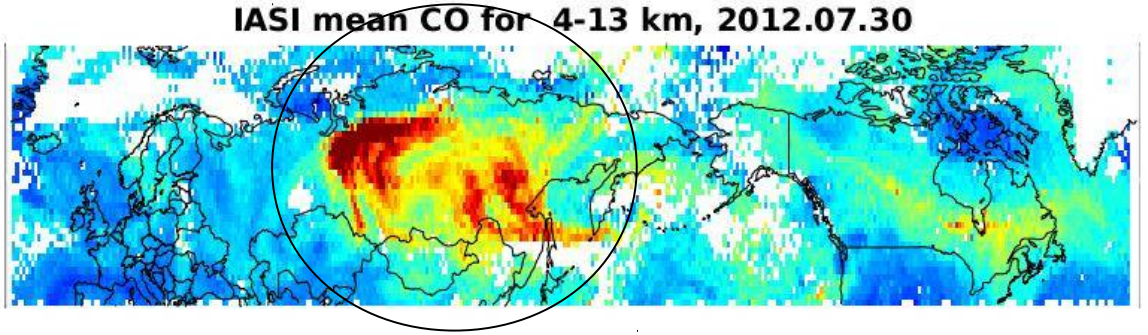

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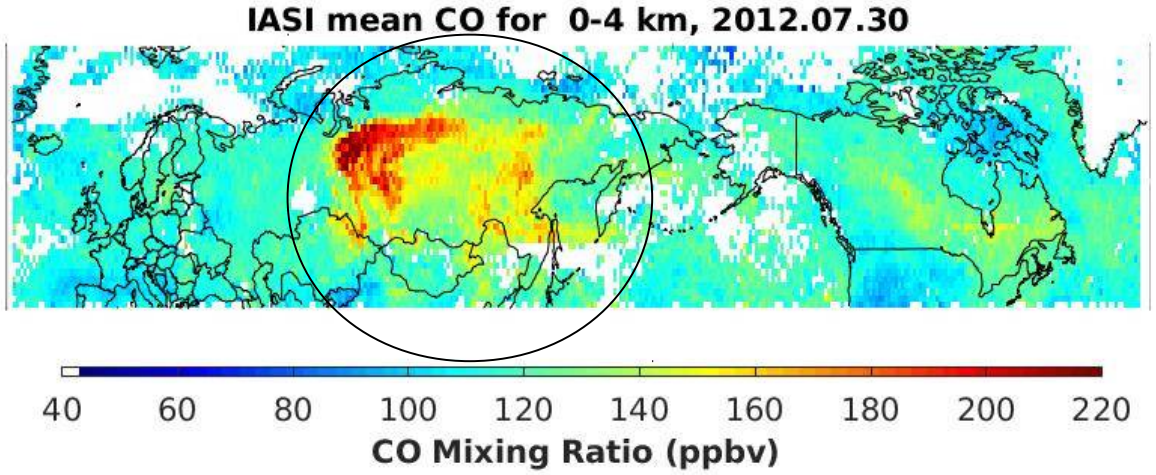

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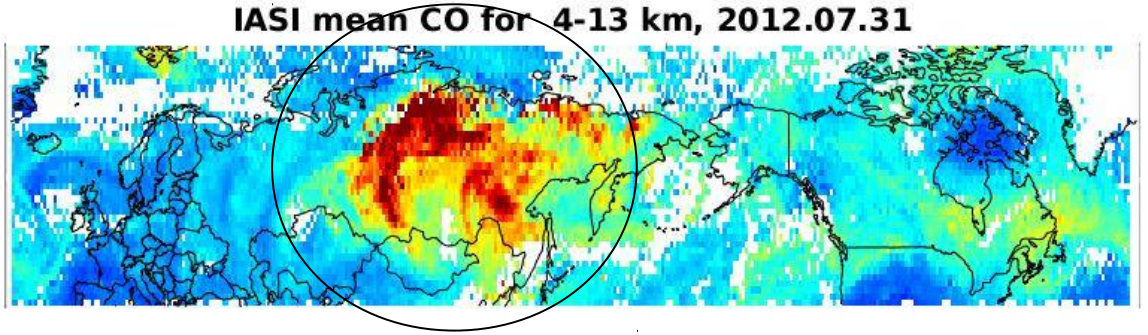

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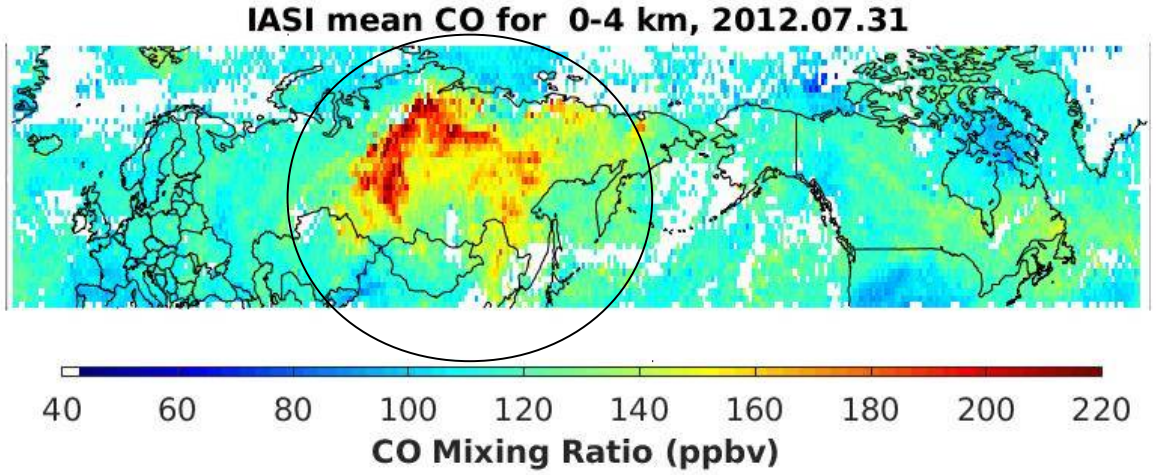

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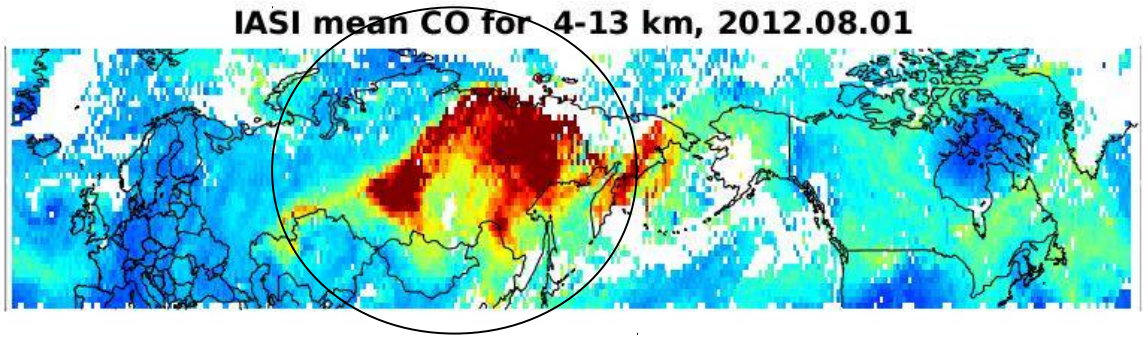

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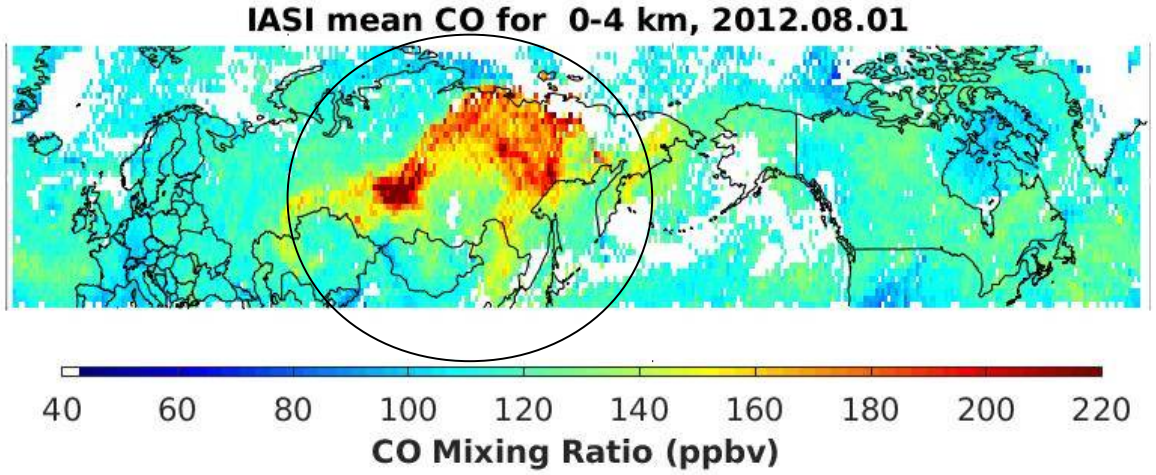

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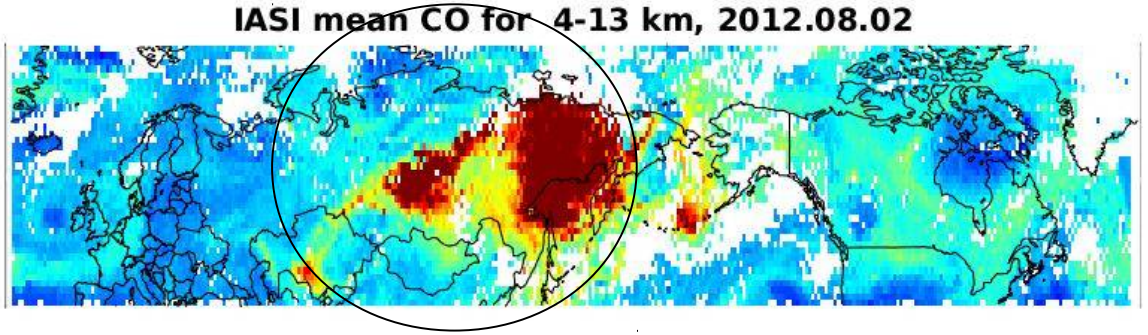

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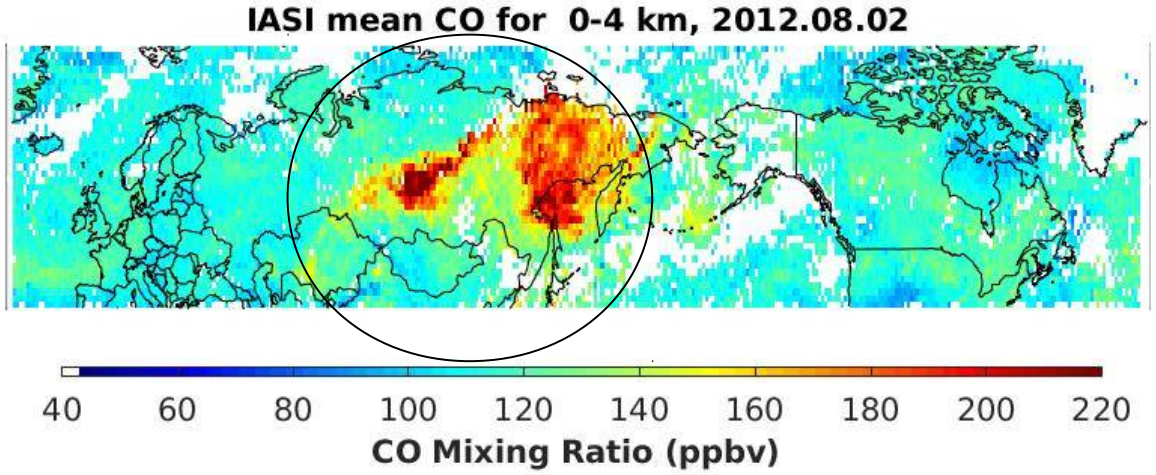

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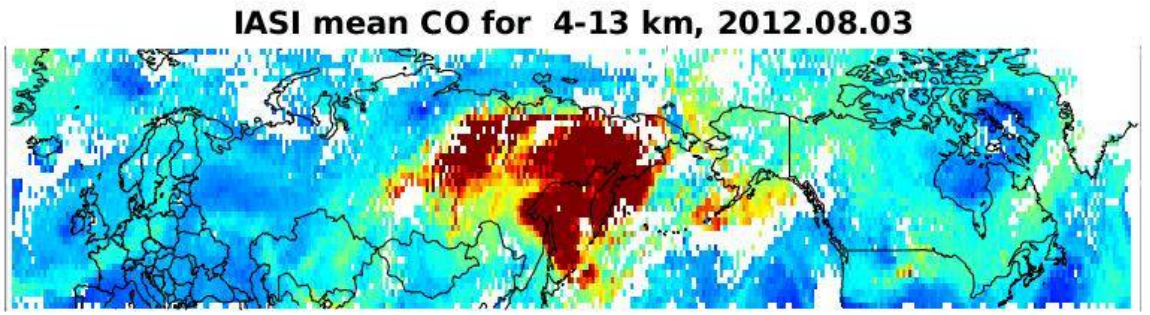

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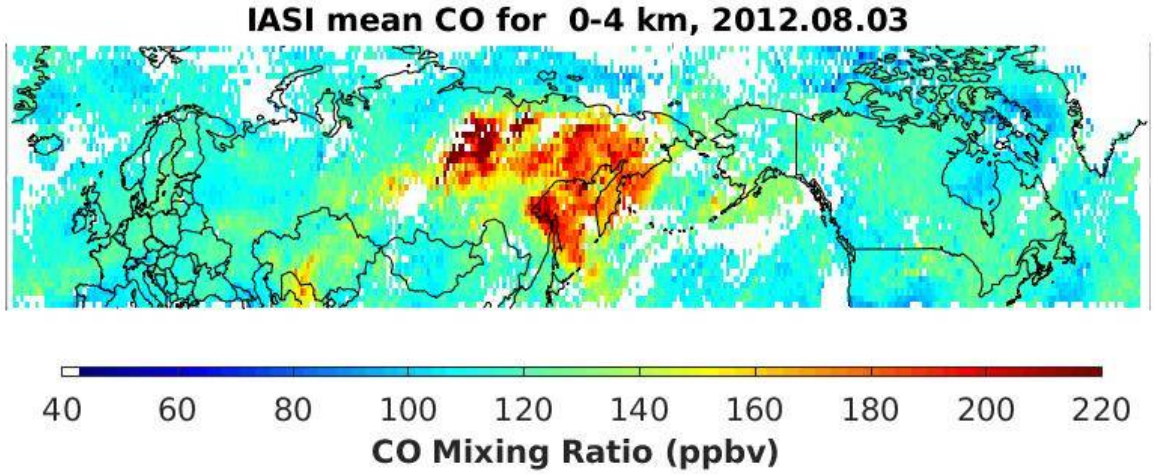

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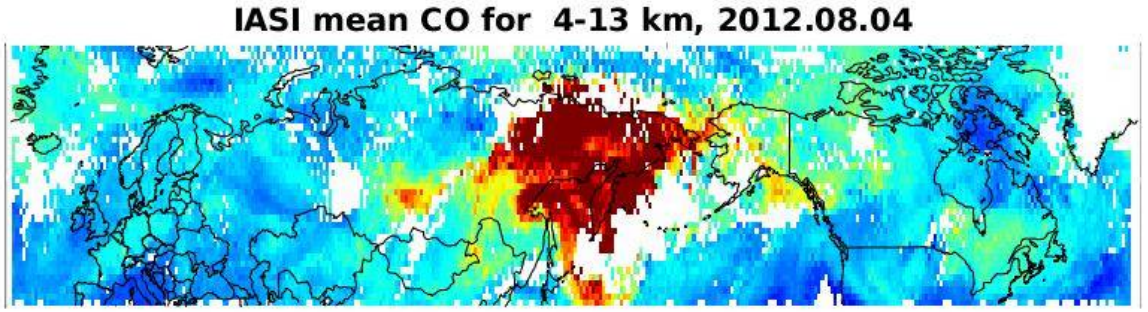

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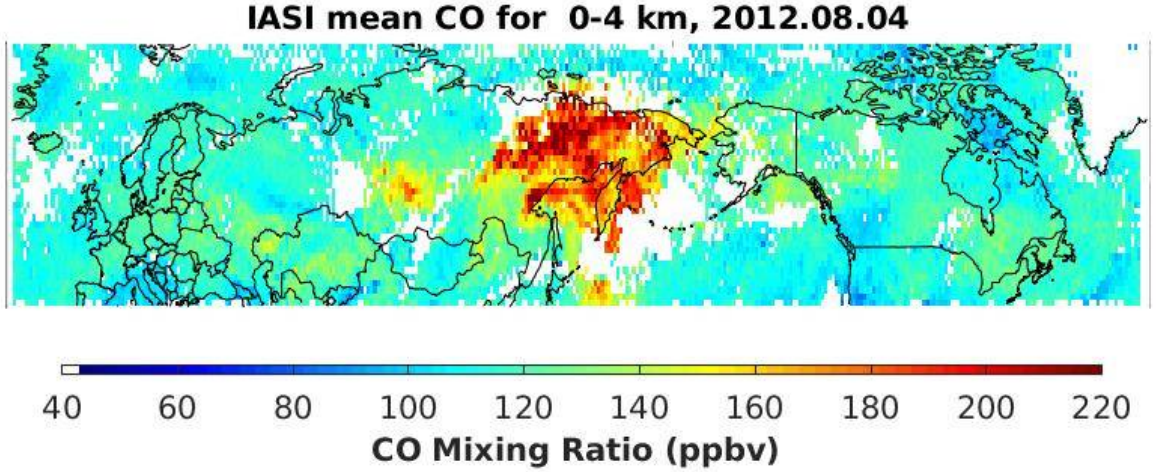

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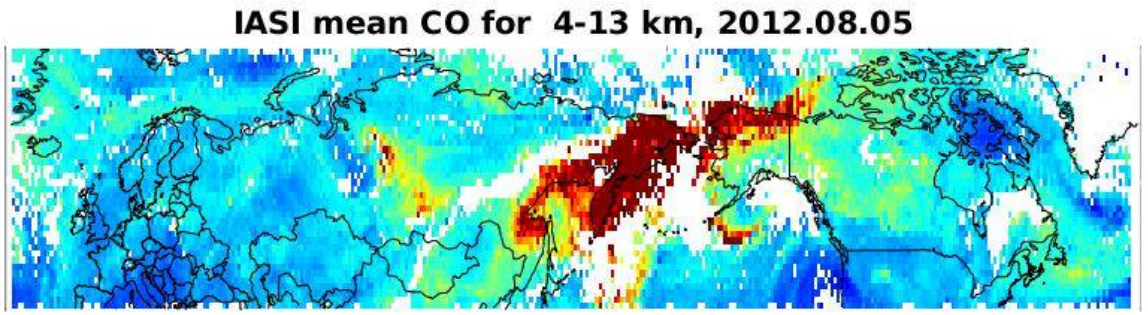

Daily IASI CO

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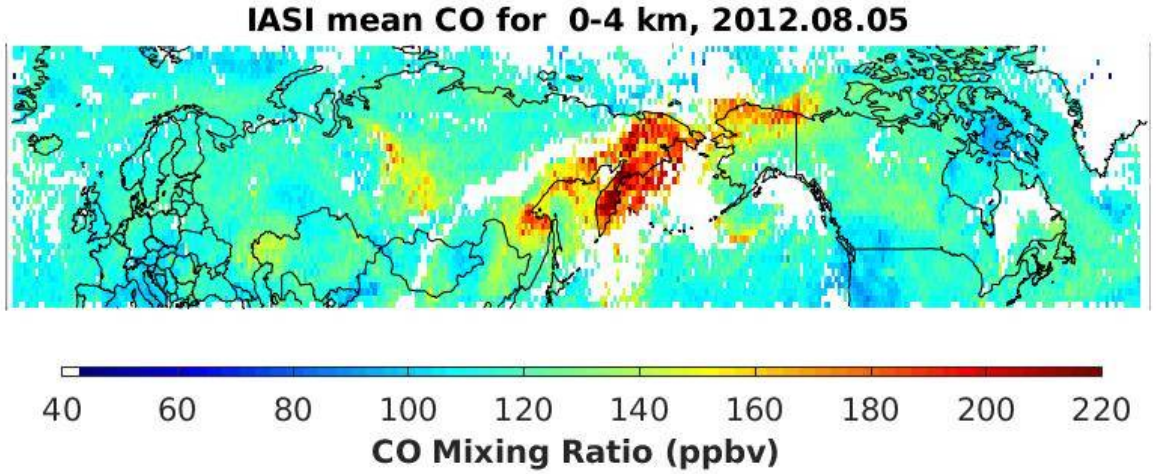

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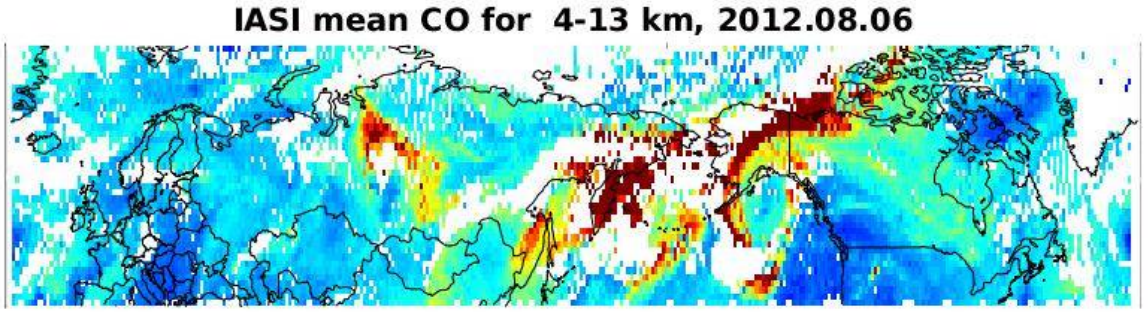

Daily IASI CO

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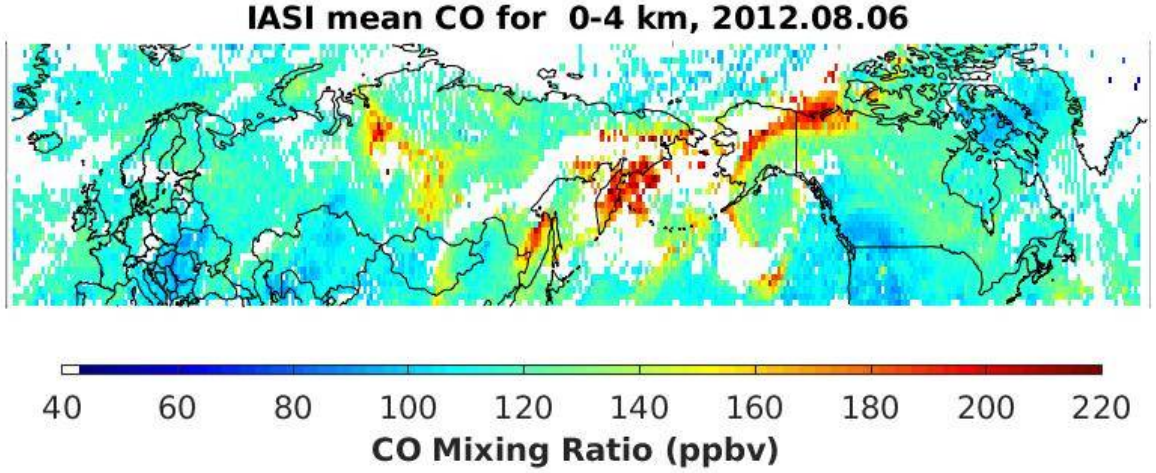


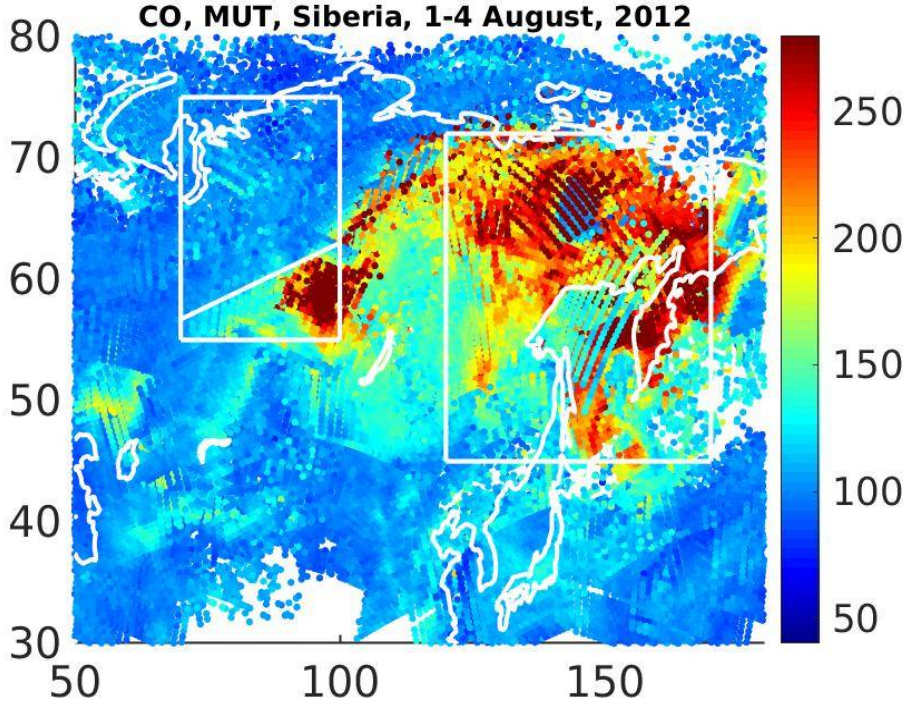
For lower troposphere:

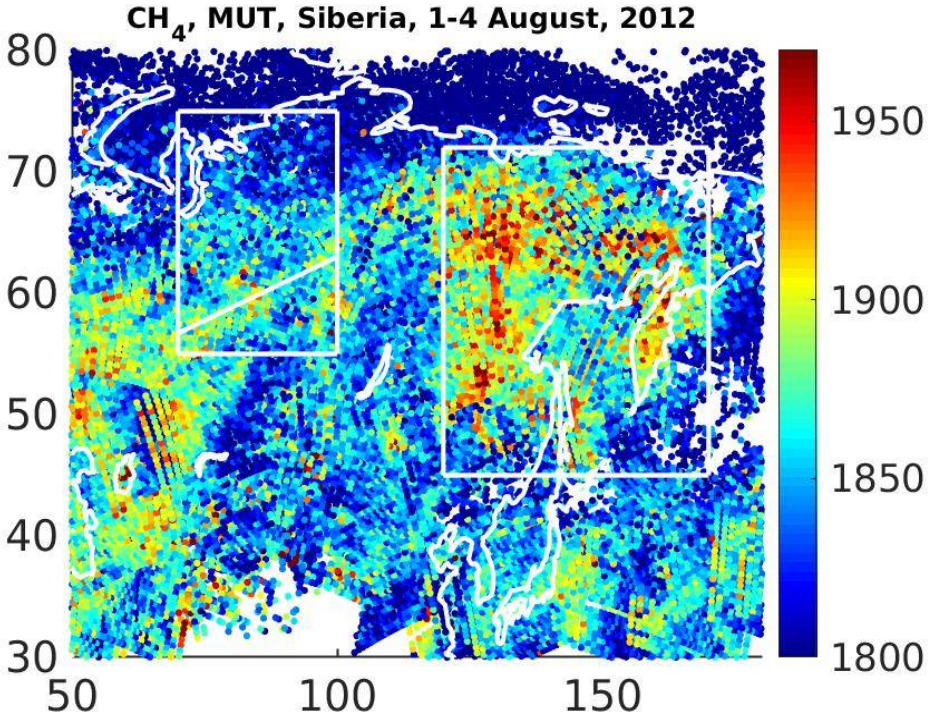
IASI observations during this severe wildfire allows one to estimate emission ratios of CH4 to CO.

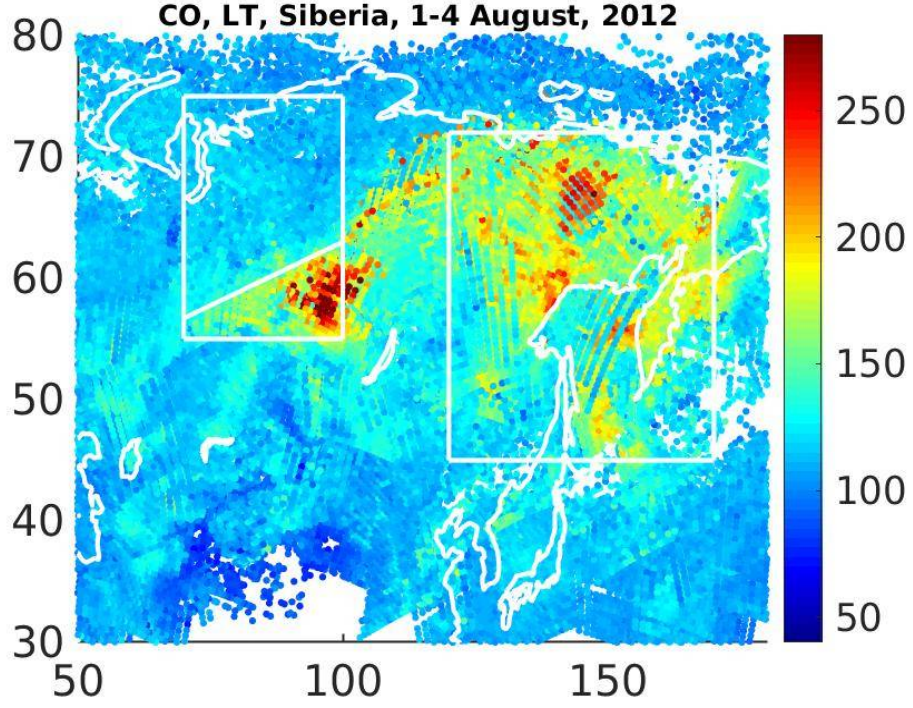
Almost all CO is a product of incomplete combustion during the fire. CH4 is a result of high-temperature destruction of organics during the same fire.

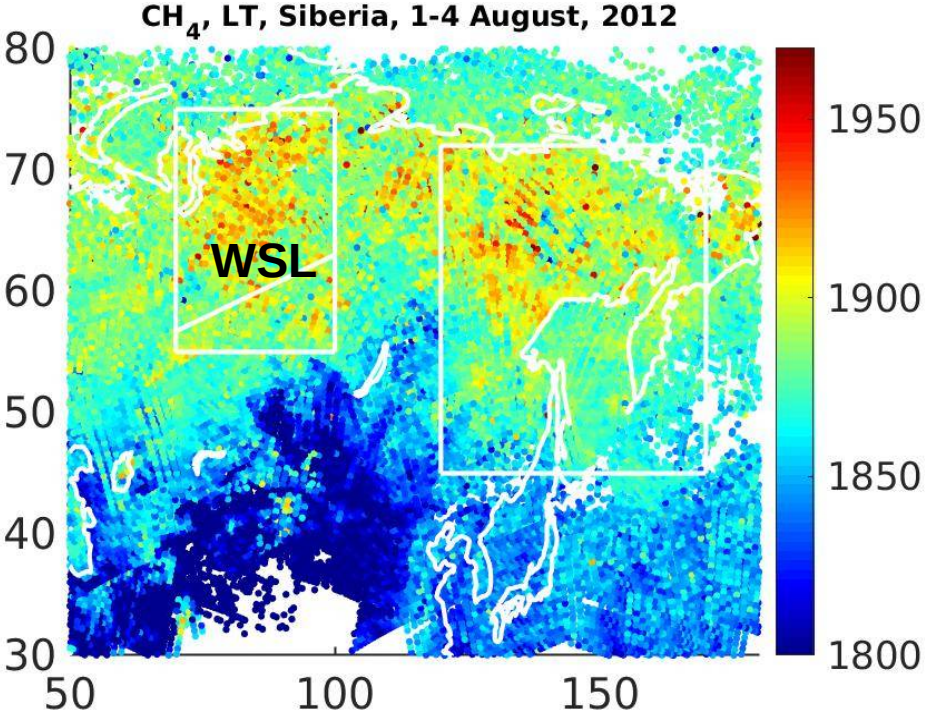
From the other hand, in August CH4 is emitted from the West Siberian Wetland, as a by-product of microbial activity in inundated soil.

Siberian 2012 wildfires, IASI CO and CH_4 maps for 1-4 Aug.

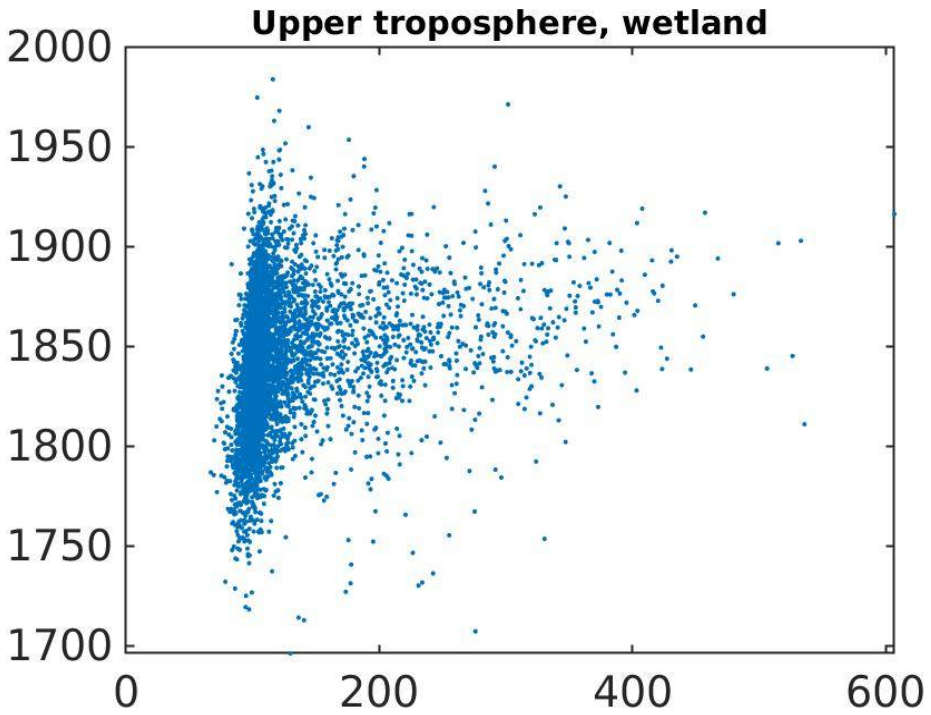


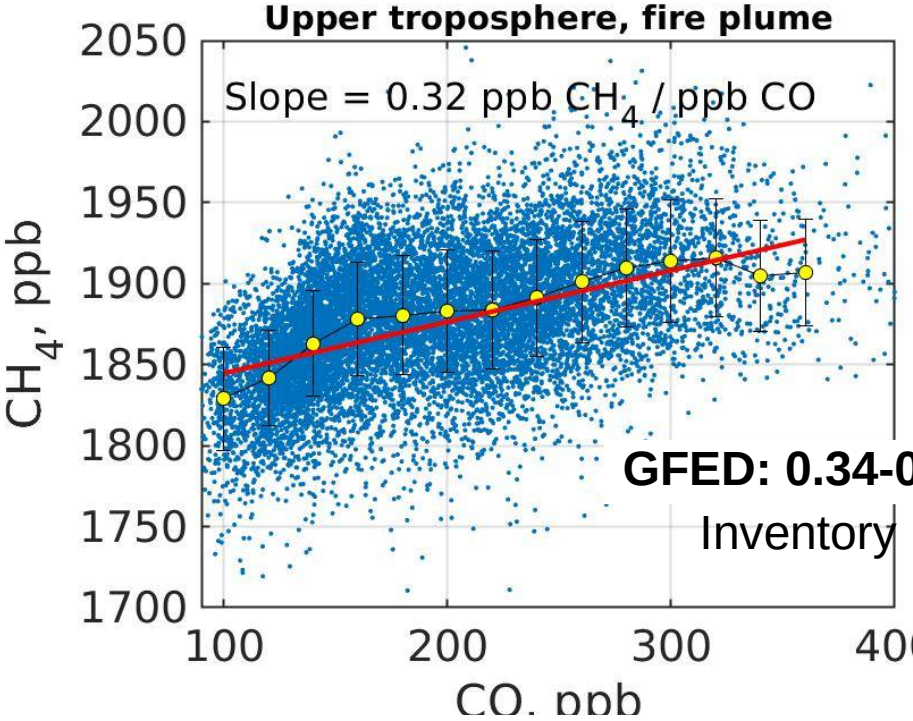






Siberian 2012 wildfires, CH_4 versus CO

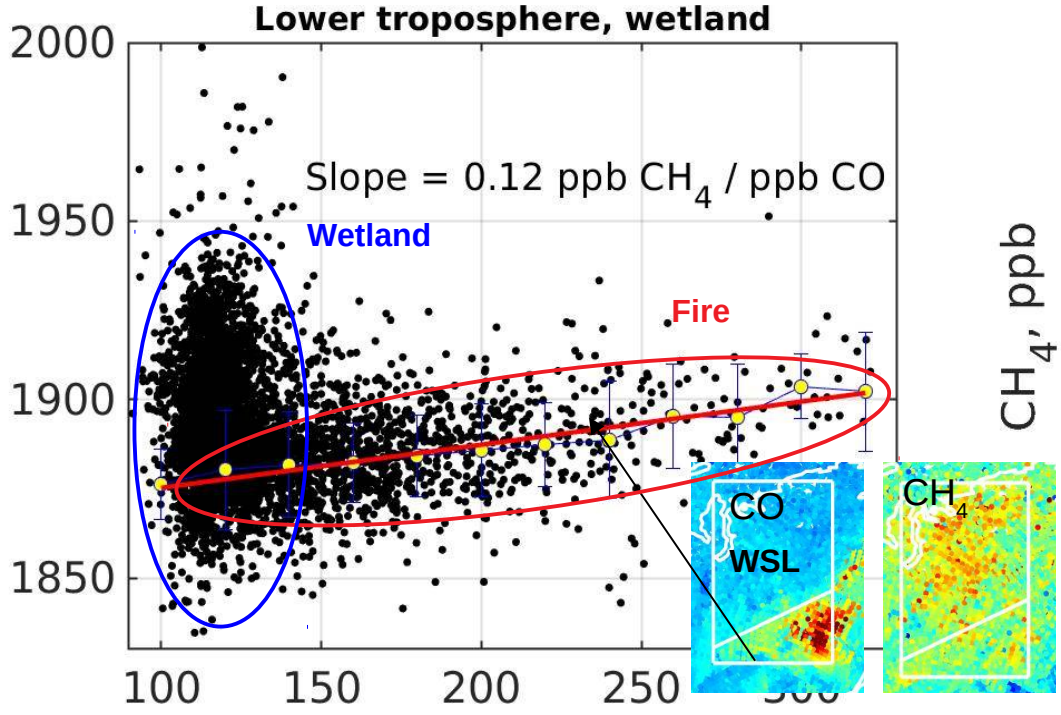


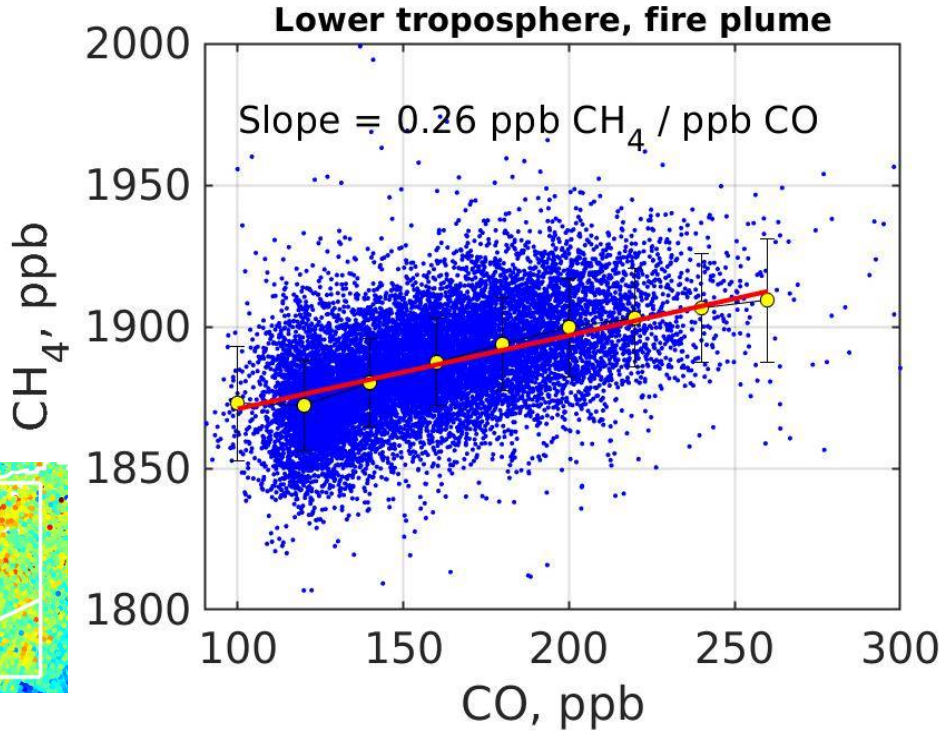


MUT

GFED: 0.34-0.69

Inventory





LT

Conclusions

TIR spectrometers are capable to supply important data on methane and carbon monoxide below 4 km of altitude. Measurements of LT methane over cold surfaces in winter or over thick Arctic ice are unfeasible.

The IASI data presented in this report evidence the following:

-**Methane Arctic trends for LT and MUT accelerated after 2013-2014 in agreement with surface data**. A temporary nature of this increase can not be ruled out, but there are no signs of that so far.

- **Seasonal maximum of methane land emission is in summer, that of marine emission is in winter.** A role of the Arctic, both terrestrial and marine in this acceleration may be significant, but quantitatively is not clear as yet. .

-**Methane anomaly over Eastern US**, defined as surplus over Pacific, **increased from 2010 to 2017**. IASI/TIR and GOSAT/SWIR are in excellent agreement. Is it a result of growing emission from US or impact of growing emission in Canadian Arctic and transport to US? This question is still open.

-**IASI observed fast ascending of CO in Siberian wildfires from LT to MUT and East-ward transport to Canada and US.**

-Methane to CO ratios in fire plumes were close to 0.3, that corresponds to the lower limit for emission ratios obtained by a bottom up inventory.