National Aeronautics and
Space Administration

EXPLORE EARTH

Kathy Hibbard, Chip Miller, George Hurtt, Junjiu Liu and Many Others!

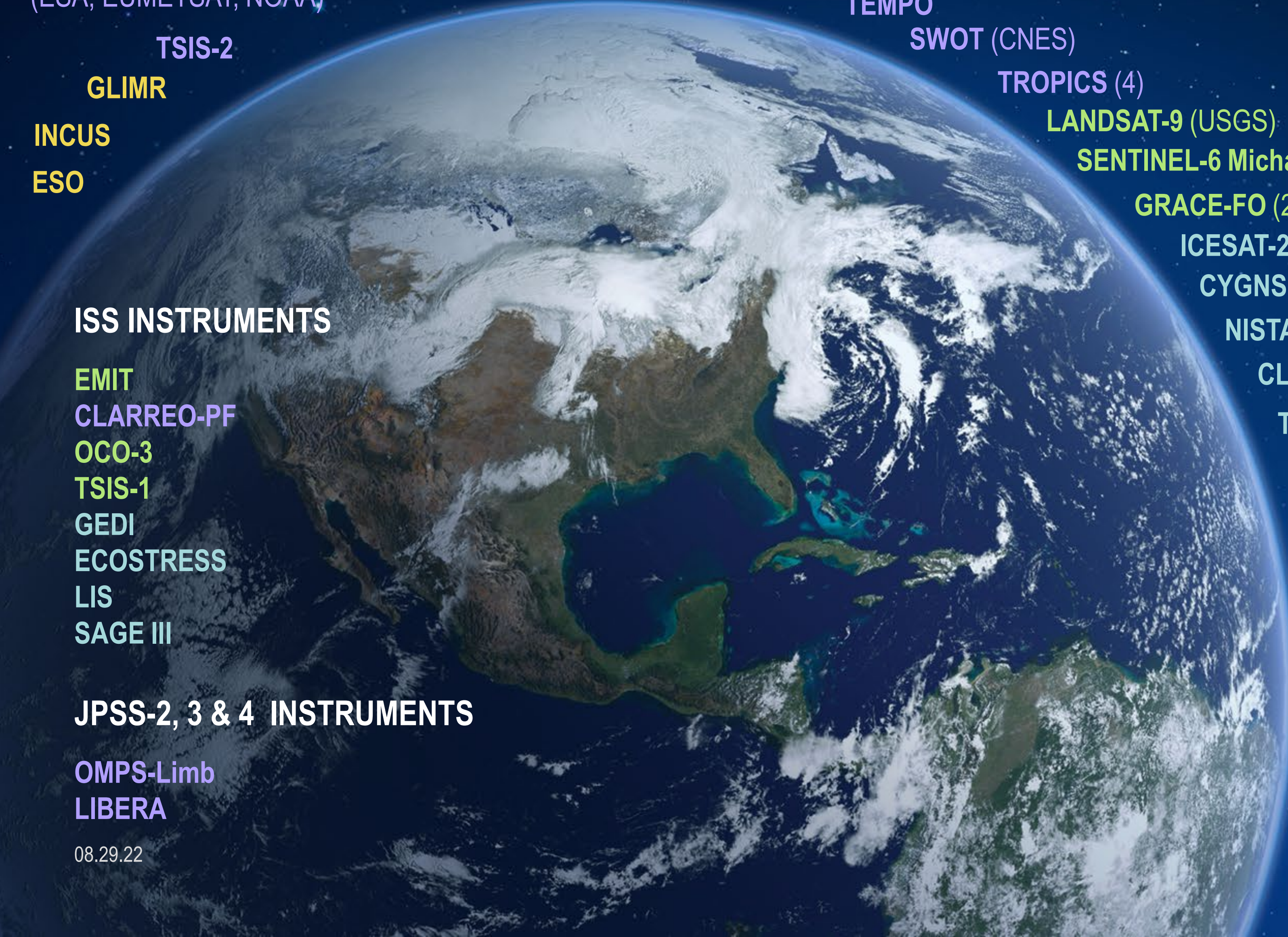
A Shallow Overview of NASA's Earth Science Division for Carbon

Fourth Carbon from Space; ESA Frascati, Italy

25 October, 2022

NASA EARTH FLEET

12 Oct, 2022



SENTINEL-6 B (ESA, EUMETSAT, NOAA)
PACE (NSO)
MAIA
GEOCARB
PREFIRE (2)
NISAR (ISRO)Z
TEMPO
SWOT (CNES)
TROPICS (4)
LANDSAT-9 (USGS)
SENTINEL-6 Michael Freilich (ESA, EUMETSAT, NOAA)
GRACE-FO (2) (GFZ)
ICESAT-2
CYGNSS (8)
NISTAR, EPIC (DSCOVR/NOAA)
CLOUDSAT (CSA)
TERRA (METI, CSA)
AQUA (JAXA, AEB)
AURA (NSO, FMI, UKSA)
CALIPSO (CNES)
GPM (JAXA)
LANDSAT 7 (USGS)
LANDSAT 8 (USGS)
OCO-2
SMAP
SUOMI NPP (NOAA)

TSIS-2
GLIMR
INCUS
ESO

ISS INSTRUMENTS

EMIT
CLARREO-PF
OCO-3
TSIS-1
GEDI
ECOSTRESS
LIS
SAGE III

JPSS-2, 3 & 4 INSTRUMENTS

OMPS-Limb
LIBERA

08.29.22

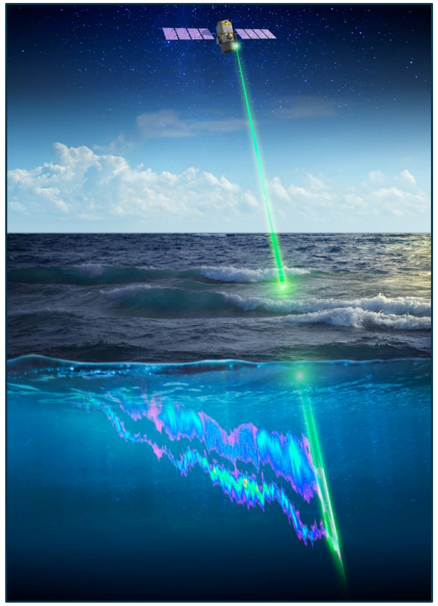
INVEST/CUBESATS

CIRiS 2023
NACHOS 2022
CTIM 2022
NACHOS-2 2022
SNoOPI* 2022
MURI-FO* 2022
HyTI* 2023

(PRE) FORMULATION
IMPLEMENTATON
PRIMARY OPS
EXTENDED OPS
*LAUNCH DATE TBD

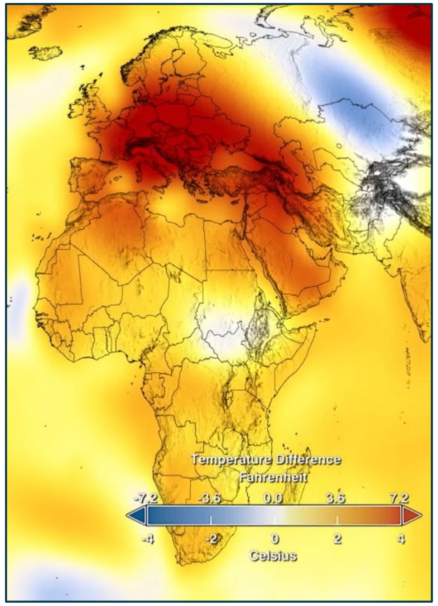
NASA Earth Science Division Elements

Flight



- Develops, launches, and operates NASA's fleet of Earth-observing satellites, instruments, and aircraft.
- Manages data systems to make data and information products freely and openly available.

Research & Analysis

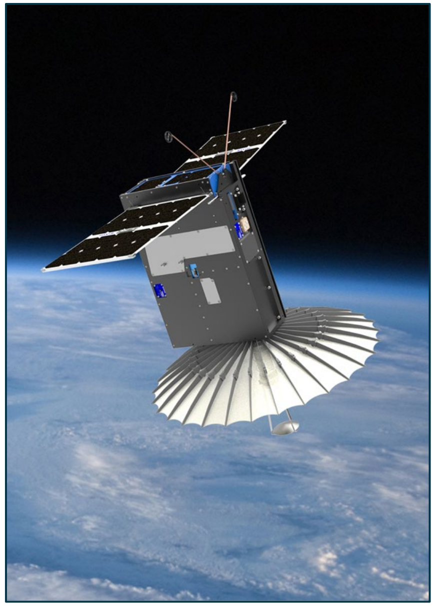


- Supports integrative research that advances knowledge of the Earth as a system.
- Includes six focus areas plus field campaigns, modeling, and scientific computing.

Applied Sciences

- Develops and supports use of Earth observations and scientific knowledge for private and public planning and decisions.
- Activities include disaster response support and capacity building.

Technology (ESTO)



- Develops and demonstrates technologies for future satellite and airborne missions: Instruments, Information Systems, Components, InSpace Validation (CubeSat and SmallSat form factors).

Research and Analysis (R&A)

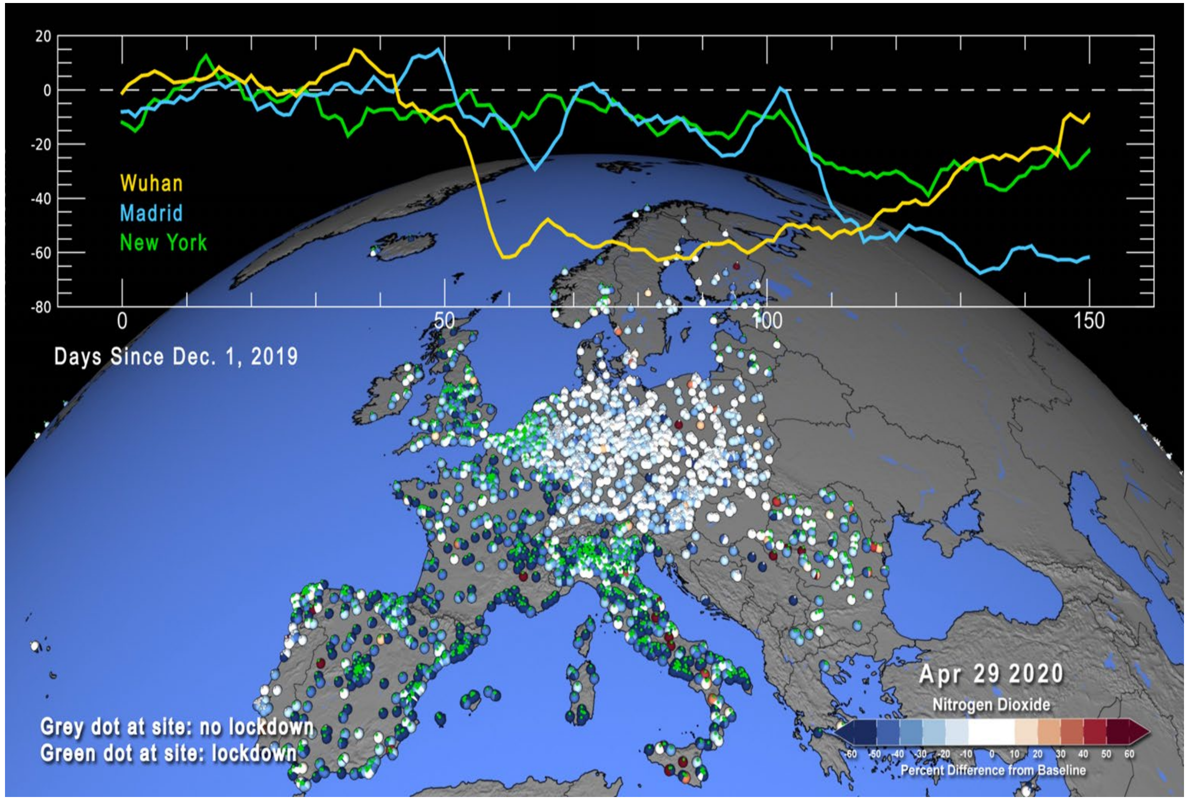
Modeling and Assimilation in R&A Focus Areas

- Climate Variability and Change (Modeling & Analysis Program, Cryosphere, Physical Oceanography, etc)
- Atmospheric Composition
- Weather and Atmospheric Dynamics
- **Carbon Cycle & Ecosystems (Terrestrial Ecology, Ocean Biology & Biogeochemistry, Biodiversity, Land Cover/Land Use Change)**
  - **Highlights from OCO, ABoVE, CMS**

Big data mining

Prediction models

- Land floods/droughts using ocean satellite information



C. Keller (USRA) **Evaluating the Impact of COVID-19 Restrictions on Air Pollution**

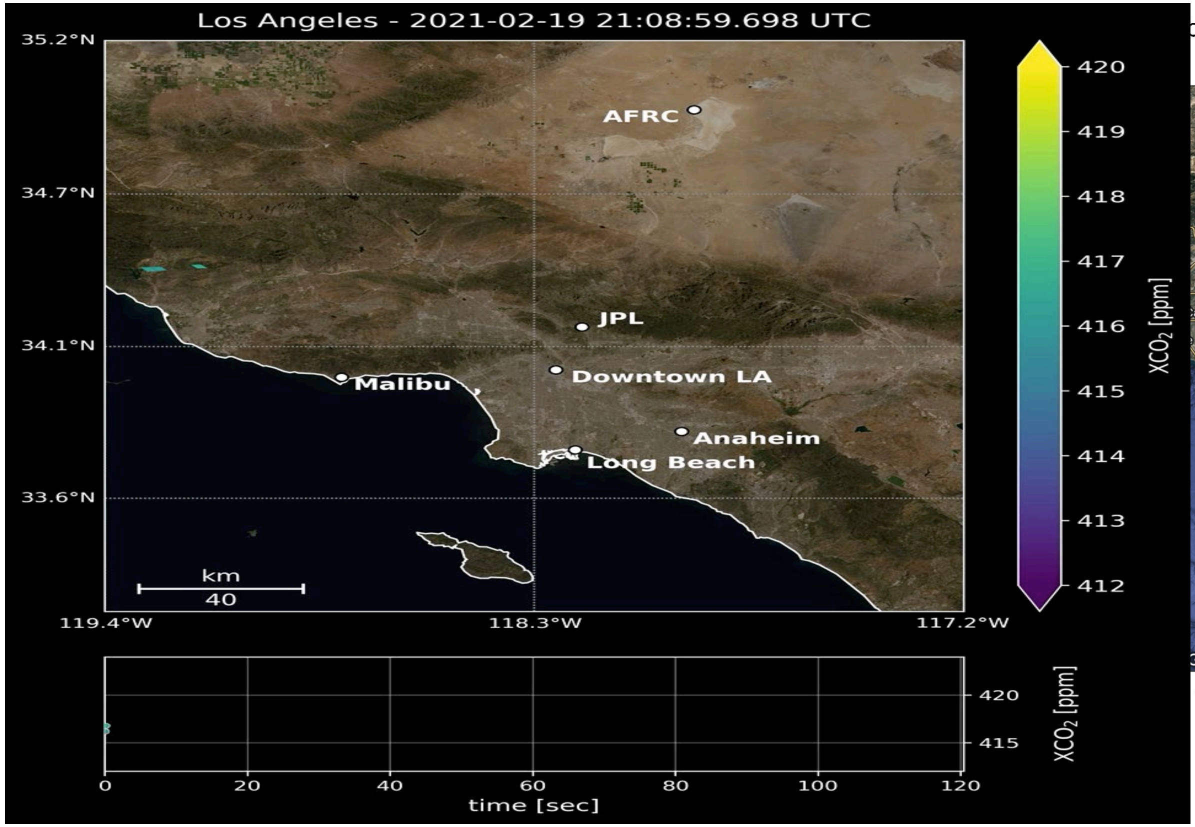
Deviation of observed surface nitrogen dioxide relative to a business-as-usual model estimate as a result of mobility restrictions in the wake of the COVID-19 pandemic. Shown are the estimated deviations on May 1, 2020 at all publicly available monitoring sites in Europe. Time series on top show daily deviations over Wuhan (yellow), Madrid (blue), and New York (green) since Dec 1., 2019. Source: https://svs.gsfc.nasa.gov/4872

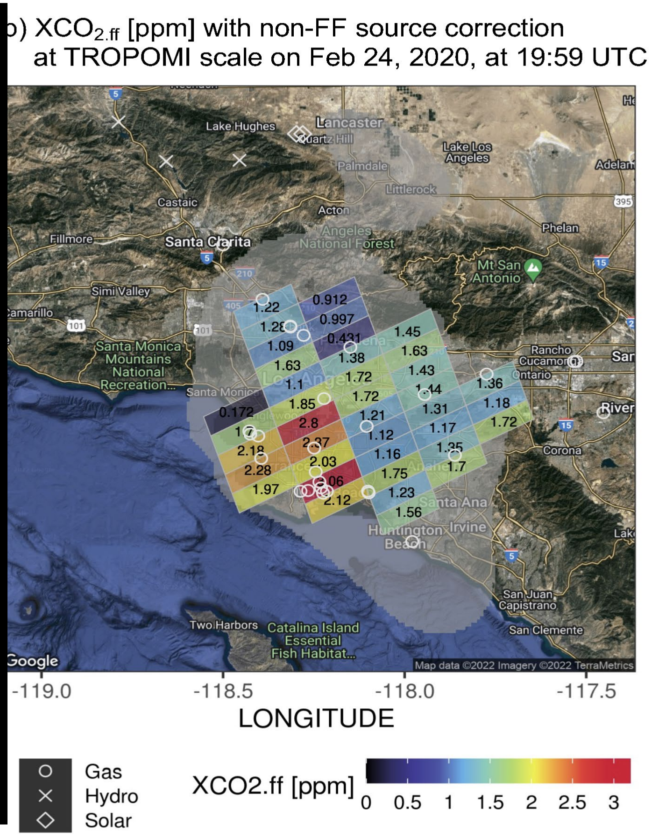
Source: ESD R&A program

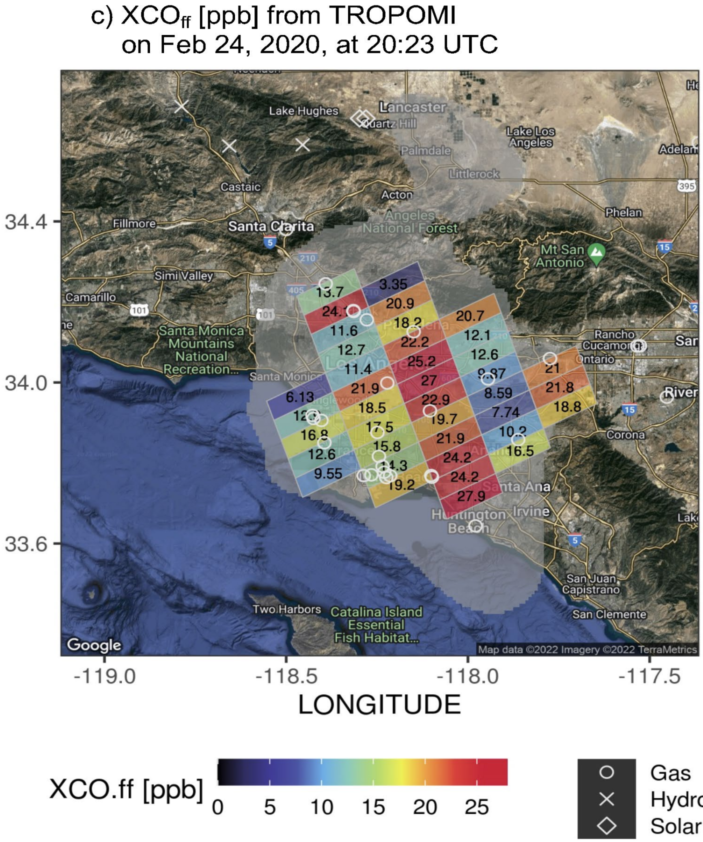
Estimating Emission Ratios and Generate Low-Latency Fossil Fuel Emissions with GHG/AQ data

XCO2 enhancement from OCO-3

XCO enhancement from TROPOMI



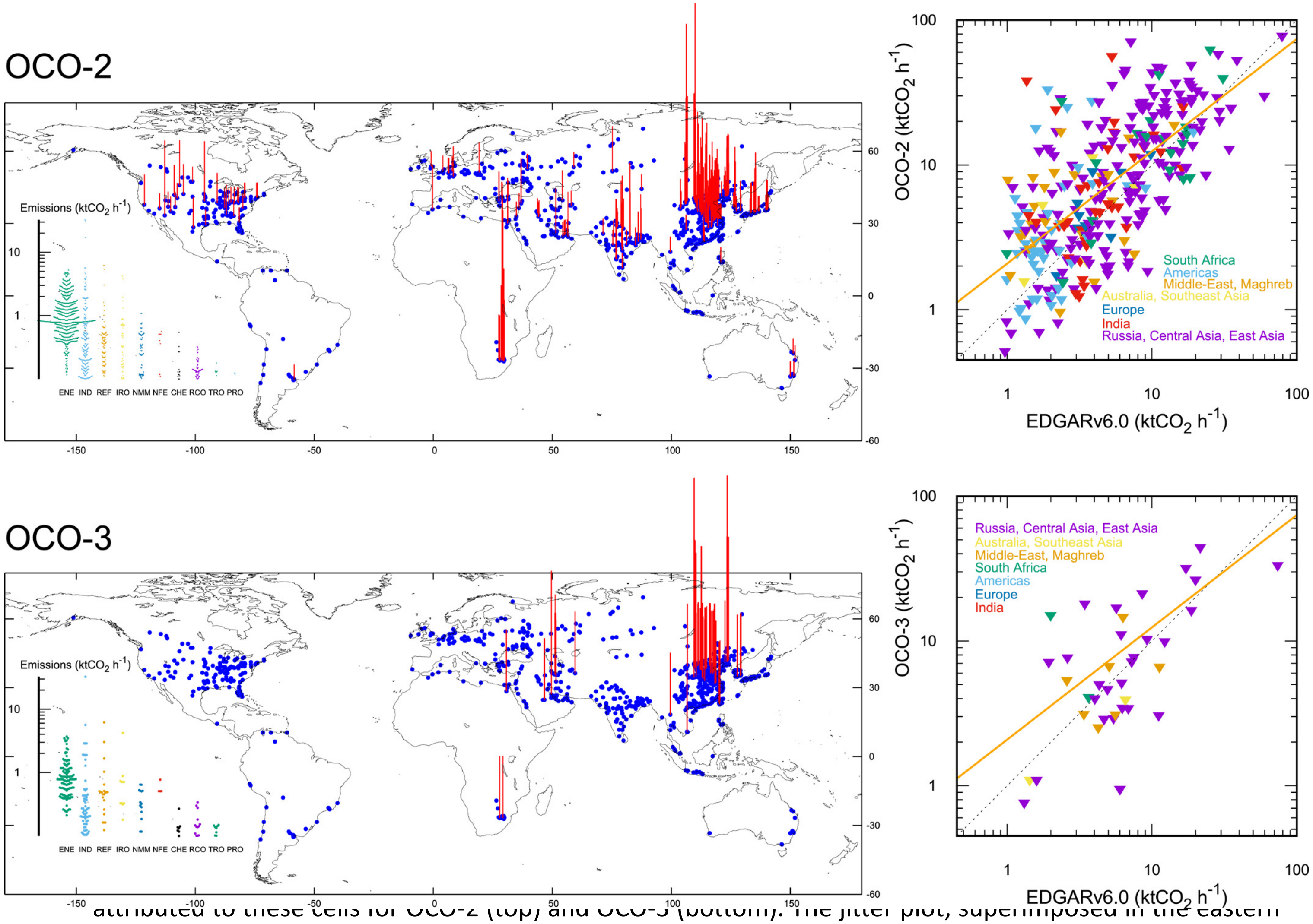




- OCO-3 SAM mode and TROPOMI XCO observations; Estimate emission ratios within the city;
- Emission ratios could be used to quantify contribution from different sectors;

Wu et al., 2022

CO_2 Emitters as seen from



attributed to these cells for OCO-2 (top) and OCO-3 (bottom). The jitter plot, superimposed in the eastern Pacific part of each map shows the distribution of the emissions per sector from various industries. The scatter plots on the right are for the retrieved emission values versus the inventory values for OCO-2 (top) and OCO-3 (bottom), with colors reflecting the geographical location.

Science Question: The Paris Climate Agreement has increased the need to monitor emissions from fossil fuel combustion around the world. How reliable are OCO-2 and OCO-3 for observing emission plumes from large point sources and intense urban area sources?

Data & Results: A simple emission estimation scheme is implemented on the multi-year archive of OCO-2 and OCO-3. The emission estimates explain a large part of the variability of a global emission inventory (EDGAR) with differences between retrieval estimates and inventory mostly random.

Significance: The study shows that trends can therefore be calculated robustly in areas of favorable observation conditions, especially with the increasing time span of the OCO-2 and OCO-3 data. In addition, OCO-3 cases display a consistent increase in emissions from morning plumes to afternoon plumes, highlighting its ability to capture the diurnal component of emission estimates.

Chevallier, F., et al. (2022). Large CO_2 emitters as seen from satellite: Comparison to a gridded global emission inventory. GRL, 49, e2021GL097540. https://doi.org/10.1029/2021GL097540

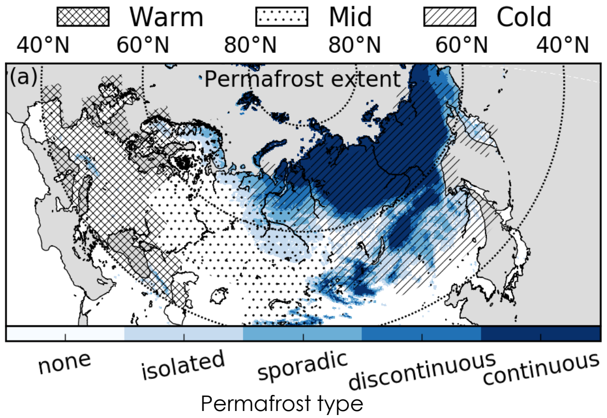
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Multi-year observations reveal a larger than expected autumn respiration signal across northeast Eurasia

Byrne et al. (2022), Biogeosciences, https://doi.org/10.5194/bg-19-4779-2022

ARCTIC – BOREAL VULNERABILITY EXPERIMENT

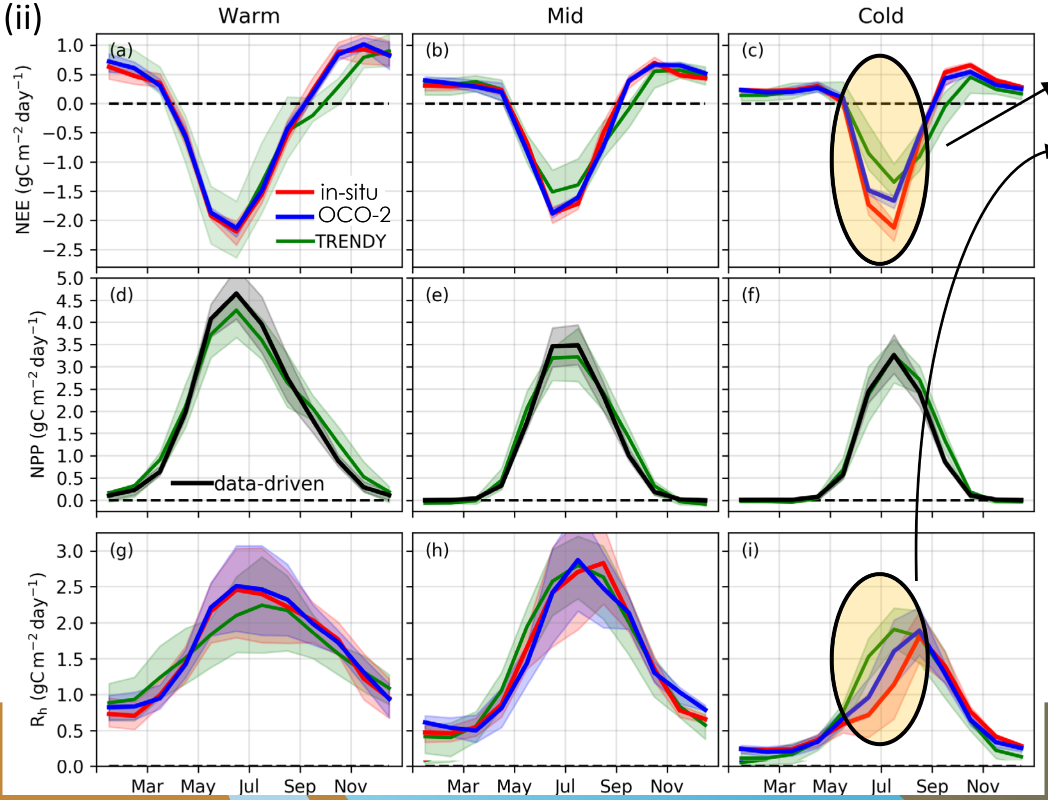
(i)



Science Question: Site-level observations have shown pervasive cold season CO_2 release across Arctic and boreal ecosystems, impacting annual carbon budgets. Still, the seasonality of CO_2 emissions are poorly quantified across much of the high latitudes due to the sparse coverage of site-level observations. This study asks: <u>can space-based remote sensing quantify seasonal carbon fluxes across data-sparse high latitude regions of northern Eurasia?</u>

Data: OCO-2 X_{CO2} measurements are assimilated in global flux inversions to estimate net ecosystem exchange (NEE). In addition, remote-sensing-based gross primary production (GPP) datasets (FluxSat, FLUXCOM, VPM, and GOSIF) are employed to decompose top-down NEE into primary production and respiration components.

(ii)



Results:

- Top-down NEE implies strong summer uptake followed by strong autumn release of CO_2 over the entire cold northeastern region of Eurasia.
- This seasonality implies less summer heterotrophic respiration (Rh) and greater autumn Rh than would be expected given an exponential relationship between respiration and surface temperature.
- This seasonality of NEE and Rh over northeastern Eurasia is not captured by the TRENDY v8 ensemble of dynamic global vegetation models (DGVMs).
- We explain mismatch against TRENDY by respiration from soils at depth during the zero-curtain period, when sub-surface soils remain unfrozen up to several months after the surface has frozen, which is not well represented in models.

Significance: This study demonstrates that space-based CO_2 & GPP datasets provide insights about the boreal-arctic carbon cycle. And confirms the existence of a significant and spatially extensive early cold season CO_2 efflux in the permafrost-rich region of northeast Eurasia that is not well represented by current DGVMs.

Congressional Direction in 2010:

Also included within the funds provided for other mission and data analysis, the conference agreement provides $6,000,000 for pre-phase A and pilot initiatives for the de … that provide statistical … sing a common …

Congressi…

None

Congressi…

The Comm… n fiscal year 2010. The…

Language…

Of the fun… levelopment of a carbo… quantification and devel… of precision and accur… ent to meet these obje… alidation datasets f… n and Forest Degradati… us far within the agenc…

Congressi…

Carbon M… … inue efforts for the de… and developm… recision and accuracy … developm… n into its operating … t these objectives. Therefore, the use of commercial off-the-shelf technologies is recommended as these products could provide robust calibration validation datasets for future NASA missions.

.

…"pilot initiatives for the development of a carbon monitoring system…"

…"replicate state and national carbon and biomass inventory processes that provide statistical precision and accuracy with geospatially explicit associated attribute data…"

…"development of a prototype Monitoring Reporting and Verification (MRV) system which can provide transparent data products achieving levels of precision and accuracy required by current carbon trading protocols…."

…"[development of] a plan…incorporating such a [MRV] system into its operating plan and long-term budget projection…"

NASA-CMS Phase 1

Biomass Pilot. *The goals of the Biomass Pilot are to:*

- Utilize satellite and in situ data to produce quantitative estimates (and uncertainties) of aboveground terrestrial vegetation biomass on a national and local scale.
- Assess the ability of these results to meet the nations need for monitoring carbon storage/sequestration.

Flux Pilot. *The objectives of the Flux Pilot are to:*

- Combine satellite data with modeled atmospheric transport initiated by observationally-constrained terrestrial and oceanic models to tie the atmospheric observations to surface exchange processes.
- Estimate the atmosphere-biosphere CO_2 exchange.

Scoping Efforts. *The objectives of the Scoping Efforts are to:*

- Identify research, products, and analysis system evolutions required to support carbon policy and management as global observing capability increases.

Hurtt et al. (2014) Phase 1 Report

NASA's Approach to CMS/MRV

- Recognizes that a sustained, observationally-driven carbon monitoring system using remote sensing data has the potential to significantly improve the relevant information base for the U.S. and world;
- Recognizes multiple users, multiple scales, multiple quantities, and multiple frameworks for MRV (e.g. International, national and subnational, markets);
- Recognizes the importance of user engagement to be responsive to stakeholder needs;

The goal for NASA's CMS project is to prototype the development of carbon monitoring capabilities needed to support stakeholder needs for MRV.

Hurtt et al. (2014) Progress and Future Plans

Working Groups

Present:

- Biomass
- Flux
- Methane
- MRV
- Stakeholder
- Uncertainties
- Wet Carbon

Past:

- *Data/Data Management (2013-2019)*
- *Atmospheric Validation (2013-2019)*
- *External Communications (2012-2019*
- *Methane (2015-2019)*
- *MRV (2013-2019)*
- *Uncertainties/Algorithm Assessment/Inter-comparisons (2015-2019)*
- *System Framework (2012-2015)*
- *Algorithm Assessment/Inter-comparisons (2012-2014)*
- *Biomass-Flux (2012-2014)*
- *Capability Risk (2012-2014)*
- *Responsiveness (2012-2014)*
- *Uncertainties (2012-2014)*

The NASA Carbon Monitoring System Phase 2 Synthesis

Science Questions

- Four key questions: What has been attempted? What major results have been obtained? What major gaps and uncertainties remain? and What are the recommended next steps?

Analysis

- ‘Phase 2’ activities (2011–2019): 79 projects, 482 publications and 136 products.
- Products reviewed hierarchically first within theme, then by theme, and finally at the initiative level. Themes included: land biomass, atmospheric flux and methane, stakeholder, and oceans/wet carbon. Additional metrics included: domain, resolution, citation, downloads, and application readiness level (ARL)

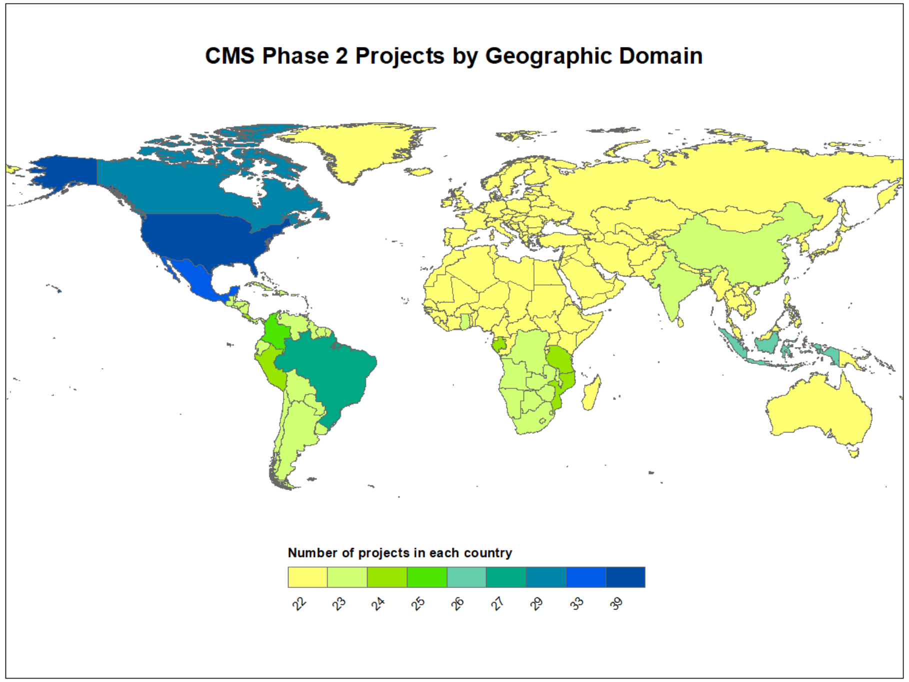


Figure: Number of CMS Phase 2 projects by geographic domain. There are 22 global projects and additional projects in various countries.

Hurtt, G.C., A. Andrews, K. Bowman, M. E. Brown, A. Chatterjee, V. Escobar, L. Fatoyinbo, P. Griffith, M. Guy, S. P. Healey, D. J. Jacob, R. Kennedy, S. Lohrenz, M. E. McGroddy, V. Morales, T. Nehrkorn, L. Ott, S. Saatchi, E. Sepulveda Carlo, S. P. Serbin, H. Tian (2022) *Environmental Research Letters*, 17, 063010. https://doi.org/10.1088/1748-9326/ac7407

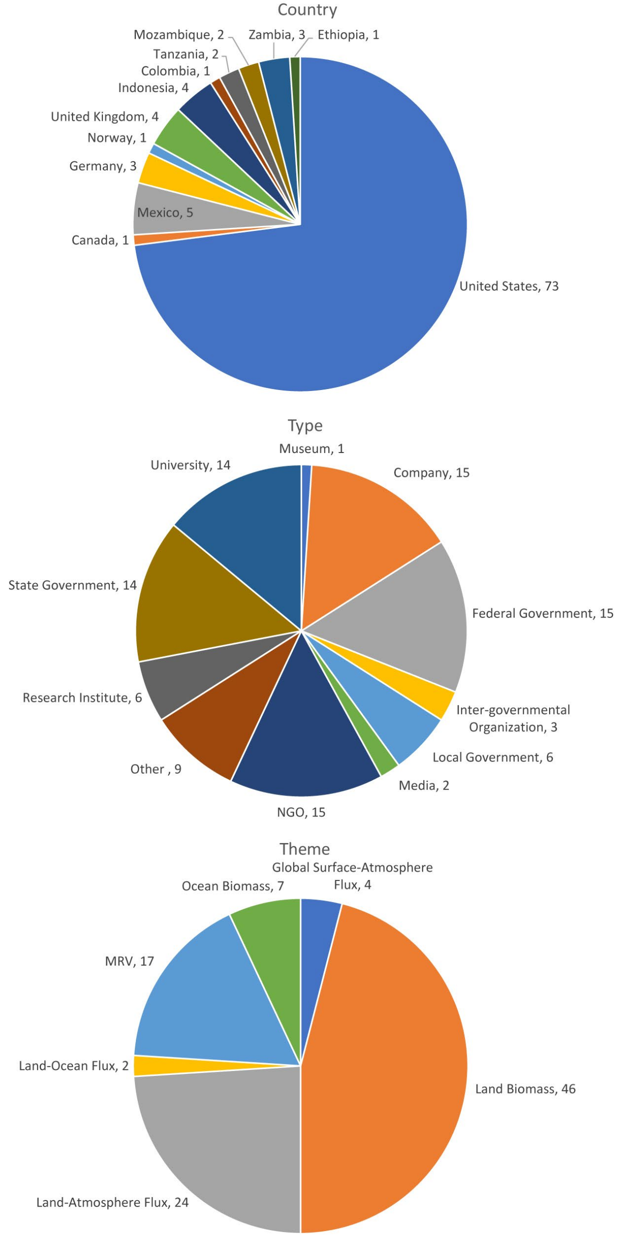
The NASA Carbon Monitoring System Phase 2 Synthesis, Cont'd

Results

- Engaged large and diverse set of scientists and stakeholders (132) from multiple themes, counties, and organizations.
- Numerous projects/products globally (22/37), in the US (31/60), and internationally (26/39) including 15 at highest ARL.
- Multiple qualitative successes: mapping forest biomass in AK, forest carbon monitoring for Maryland/RGGI, US cropland carbon flux and export, US methane reporting, Indonesian fire emissions, global wetland carbon mapping, international framework for MRV, and more.
- Different policy needs at different scales drive important differences in science requirements
- Importance and challenges of sustaining key advances and meeting additional/future needs
- >125 specific points related to scope, findings, gaps, and next steps.

Significance

- NASA CMS is one of the most ambitious relevant science initiatives to date, exploiting the major strengths of the NASA Earth Science program, while partnering with other agencies, institutions, and stakeholders.
- CMS has demonstrated that addressing stakeholder needs and advancing science for carbon are mutually beneficial, with societal needs driving new science requirements and resulting in new scientific results of high societal relevance.



Phase II: CMS stakeholders by type, theme, and country.

Acknowledgements
This work was supported by NASA Carbon Monitoring System Projects (80NSSC17K0710, 80NSSC21K1059, NNX14AO73G, 80NSSC17K0711, 80NSSC20K0006, 80NSSC21K0965 80HQTR21T0066, 80HQTR18T0016, NNX16AQ25G, 80NSSC21K1001)

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NASA EARTH

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Backup Slides

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Multi-year observations reveal a larger than expected autumn respiration signal across northeast Eurasia

Byrne et al. (2022), Biogeosciences, https://doi.org/10.5194/bg-19-4779-2022

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Citation:
Byrne, B., Liu, J., Yi, Y., Chatterjee, A., Basu, S., Cheng, R., Doughty, R., Chevallier, F., Bowman, K. W., Parazoo, N. C., Crisp, D., Li, X., Xiao, J., Sitch, S., Guenet, B., Deng, F., Johnson, M. S., Philip, S., McGuire, P. C., and Miller, C. E.: Multi-year observations reveal a larger than expected autumn respiration signal across northeast Eurasia, Biogeosciences, 19, 4779–4799, https://doi.org/10.5194/bg-19-4779-2022, 2022.

Data Sources:
TRENDY v8 gridded data were accessed by contacting Stephen Sitch following the TRENDY data policy described on their website: https://sites.exeter.ac.uk/trendy (Sitch et al., 2022). v9 OCO-2 MIP fluxes were downloaded from https://gml.noaa.gov/ccgg/OCO2_v9mip/ (Crowell et al., 2022). GFED data were downloaded from https://www.globalfiredata.org/ (Randerson et al., 2022). We downloaded version 10 of the ACOS OCO-2 lite files from the GES DISC (https://doi.org/10.5067/W8QGIYNKS3JC, OCO-2 et al., 2018). OCO-2 data were produced by the OCO-2 project at the Jet Propulsion Laboratory, California Institute of Technology, and obtained from the OCO-2 data archive maintained at the NASA Goddard Earth Science Data and Information Services Center. FluxSat data were downloaded from https://avdc.gsfc.nasa.gov/pub/tmp/FluxSat_GPP/ (Joiner, 2022). The GOSIF data product (Li and Xiao, 2019) is available at http://data.globalecology.unh.edu/, (Li and Xiao, 2019). ERA5-Land data are obtained from the Climate Data Store (https://doi.org/10.24381/cds.68d2bb30, Muñoz Sabater, 2019).

Technical Description of Figure:
(i) Permafrost extent over 2000–2016. Three regions are shown by different hatching patterns. The “Warm” (cross hatching) region does not have a zero-crossing date, the “Mid” (dots) region has a zero crossing date after 27 October, and the “Cold” (diagonal hatching) region has a zero-crossing date before 27 October. Note that some adjustments from these definitions are made so that the regions are contiguous. **(ii) Monthly carbon cycle fluxes** (average of 2015, 2016, and 2018; 2017 is excluded due to an OCO-2 data gap). (a–c) Mean (solid line) and interquartile range (shaded area) of NEE for the ensemble of IS (red) and LNLG (blue) v9 OCO-2 MIP and for the TRENDY ensemble (green). (d–f) NPP for the TRENDY ensemble (green) and estimated from data-driven GPP (black). (g–i) Rh simulated by the TRENDY ensemble (green) and calculated from combining the data-driven NPP with the IS (red) and LNLG (blue) v9 OCO-2 MIP NEE constraints. (j–l) Cumulative fraction of Rh over the growing season.

Scientific significance, societal relevance, and relationships to future missions:
This study demonstrates that the boreal-arctic carbon cycle can be tracked from space using atmospheric CO_2 and vegetation remote sensing datasets. The results of this analysis are also significant because we demonstrate that current dynamic global vegetation models (DGVMs) do not accurately represent seasonal carbon cycle dynamics in the permofrost-rich region of northeast Eurasia. This is of societal relevance because this regions is expected to undergo significant warming and permafrost thaw by the end of the century. Given the deficiencies of current DVGMs, projection of the carbon budget for this region may be flawed, potentially impacting warming projections resulting form different emission scenarios.