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LEMONTREE
Land Ecosystem Models based On New Theory, obseRvations and ExperimEnts

Reconstruction of a long-term spatially contiguous Solar-Induced Fluorescence (LCSIF) data over 1982-2021

Jianing Fang, Xu Lian, Youngryel Ryu, Pierre Gentine

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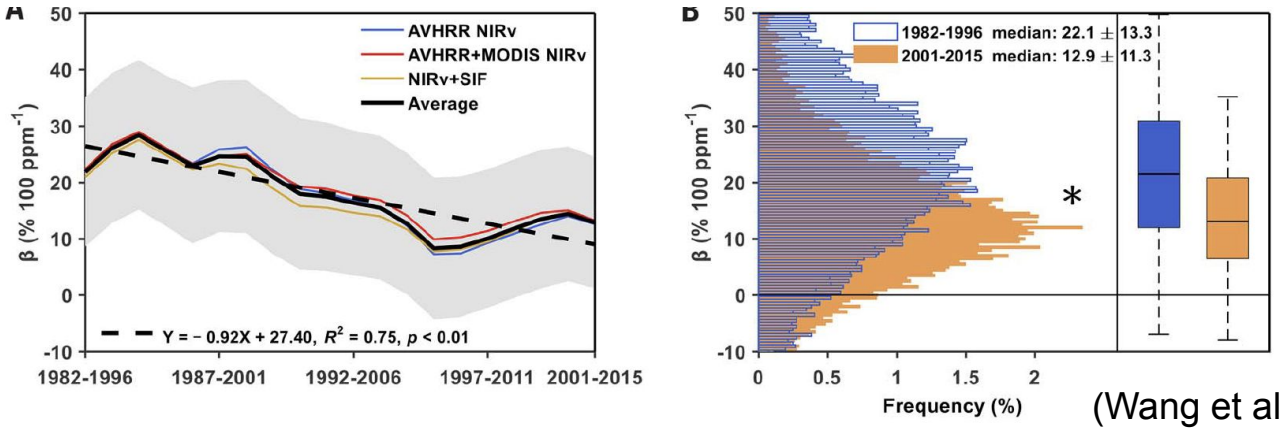
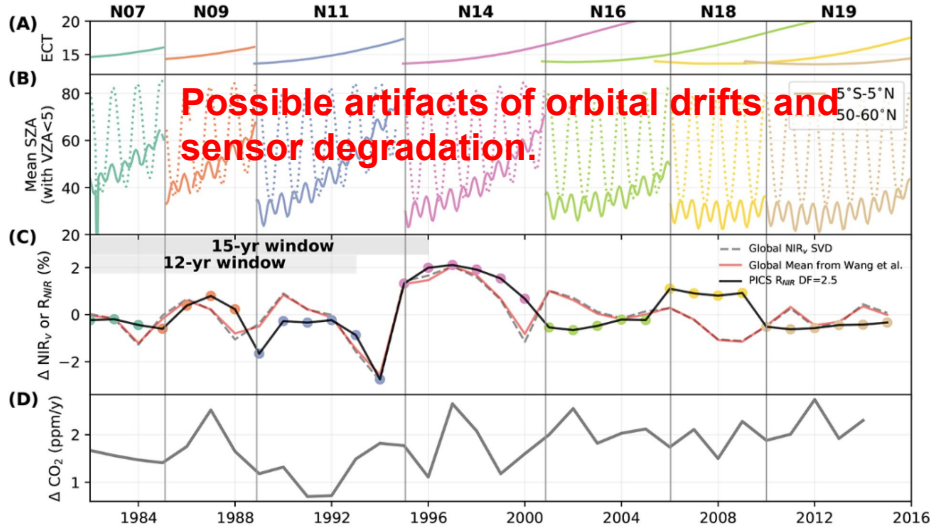
CLIMATE CHANGE

Recent global decline of CO_2 fertilization effects on vegetation photosynthesis

Songhan Wang[1,2], Yongguang Zhang[1,2,3]*, Weimin Ju[1,2], Jing M. Chen[1,4], Philippe Ciais[5],



(Wang et al., 2020)



(Frankenberg et al., 2021)

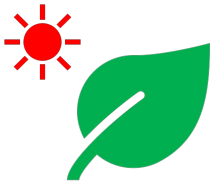
Moreover, many remote sensing proxies examined by (*5*) cannot be used to reliably estimate the effects of CO_2 on photosynthesis because they ignored the influence of CO_2 on photosynthetic light use efficiency (LUE). With the exception of EC-LUE GPP (*8*), many remote sensing proxies [illegible] importance of the CO_2 response of LUE for quantifying temporal trends in photosynthesis is well recognized (*10*, *11*) and incorporated into the DGVMs used in (*5*). Instead, most proxies examined by (*5*) more closely relate to "greenness," leaf area index, or the fraction of absorbed photosynthetically active radiation, not photosynthesis (*12*). Their results are therefore best interpreted not as a slowdown in the CFE, but as a slowdown in the rate of greening, which is widely reported and unlikely to be due to CO_2 (*13*) and has limited impact on ecosystem productivity or the carbon cycle (*6*, *14*). Although to what extent CO_2 may

Optical vegetation indices cannot represent photosynthetic changes.

(Sang et al., 2021)

Motivations: The Need for A Long-Term Solar-Induced Fluorescence Product

OCO-2 SIF
(Sun *et al*. 2017)

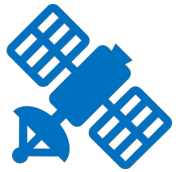


- SIF has great potential to monitor the terrestrial photosynthesis activity
- Satellite-observed SIF soundings are sparse in space & time
- SIF records are short, global observations available only since 1995, with high quality SIF series even shorter

CSIF
(Gentine *et al*. 2018; Zhang *et al*. 2018)

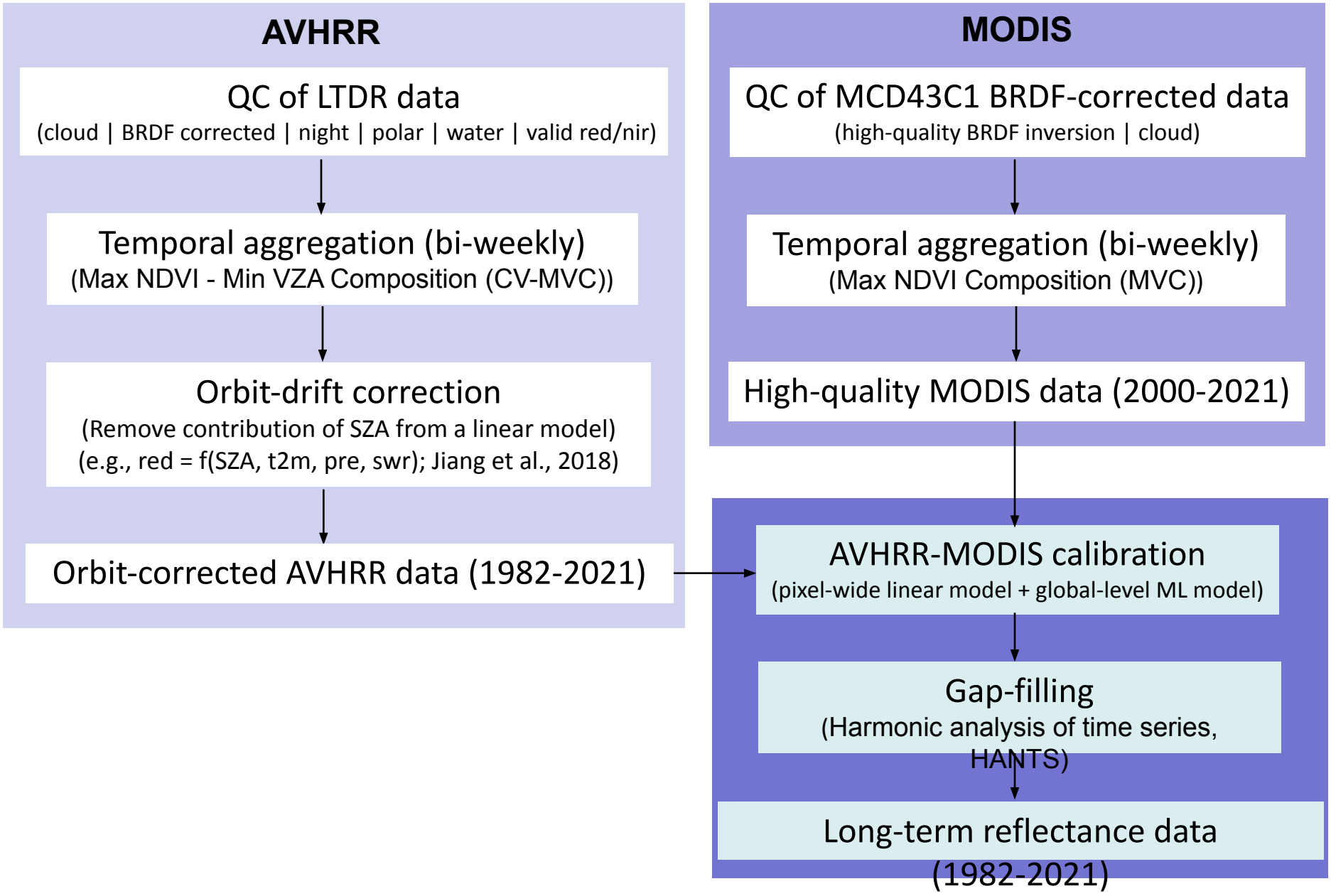
- NNs are effective noise filters that can capture the non-linear relationships between reflectance and SIF
- Successful attempts have been made to reconstruct globally contiguous SIF using MODIS
- Question remains the extent to which the reconstructed SIF can be attributed to structural or physiological changes

LCSIF
(present study)

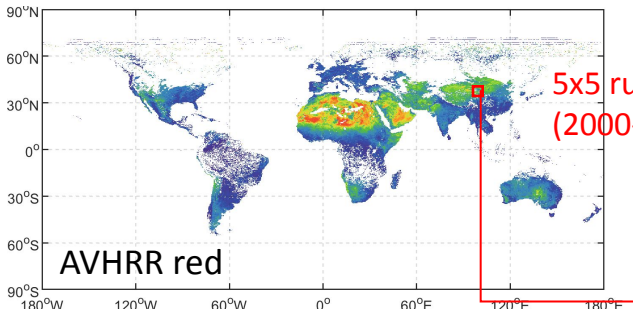


- AVHRR is marred by the lack of on-board radiometric calibration as well as the gradual or abrupt changes in SZA despite multiple rounds of correction
- Only two bands in the Red and NIR regions are available. Its broad bands made the reflectance signal susceptible to water vapor contamination

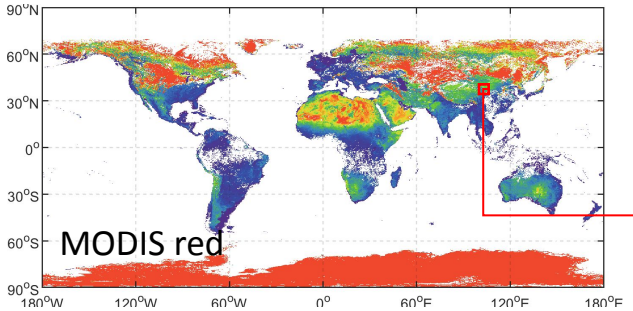
Data processing of AVHRR and MODIS reflectance



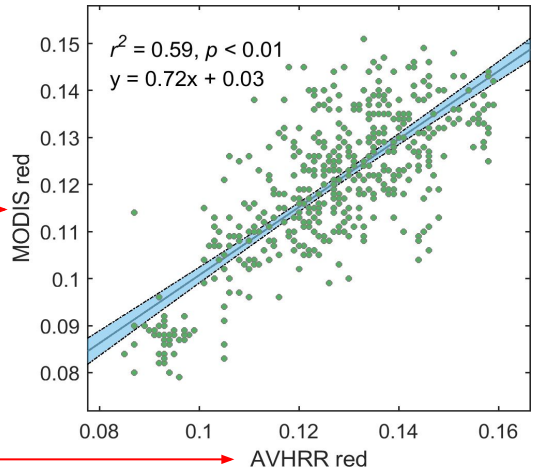
Calibration of AVHRR bands against MODIS bands



5x5 running window
(2000-2021)



Pixel-wise linear model



$Y_{residual}$ = MODIS value – linearly-corrected AVHRR value

Global-level ML model

$Y_{residual}$ = f(aerosol optical depth, snow depth, cloud cover, elevation, aridity index)

Double-correction for AVHRR bands using ML-predicted $Y_{residual}$

Data sources:

Cloud cover and snow depth: ERA5, 0.25°, hourly

AOD: MERRA-2, 0.5 x 0.625 °, 3-hour

Elevation: Global 30 Arc-Second Elevation (GTOPO30), 1km

Aridity index: Terraclimate, ~4km

Regirded to 0.05°using a cubic function

NN-based Reconstruction of LCSIF

Red+ NIR MCD43C1
BRDF-corrected Reflectance

Cloud-Free OCO2 SIF 757nm + cos(SZA)
(2015-2020 for Training + Validation2014,2020,2021 for Test)
nadir-mode | re-gridded to 0.05° | remove grids <5 soundings

Long-term reflectance data (1982-2021)
Predicted cos(SZA) based on latitude & overpass time

Train/Evaluate SIF prediction model
3-layer FCNN | 64 neurons | ReLU activation |
batch: 1024 | lr: 1e-3 | Adam Optimizer

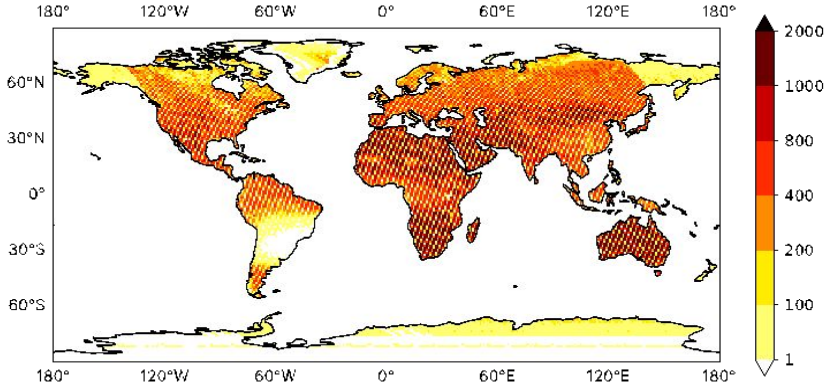
Calibrated SIF prediction model

$\overline{F}_s$

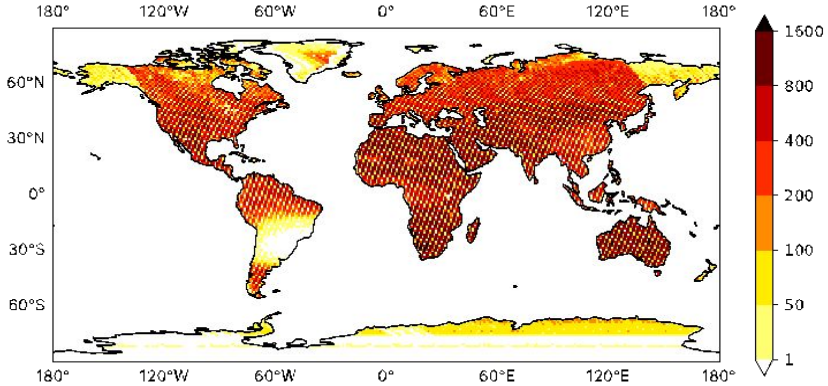
$LCSIF_{clear\text{-}inst}$

$LCSIF_{clear\text{-}daily}$

No. Train+Val Samples 0.05 °

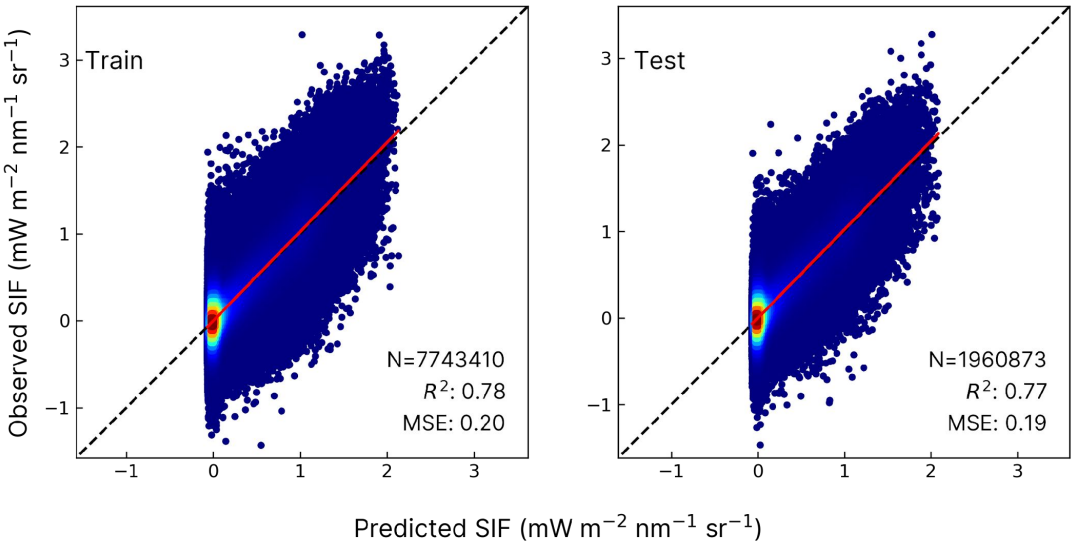


No. Test Samples 0.05 °

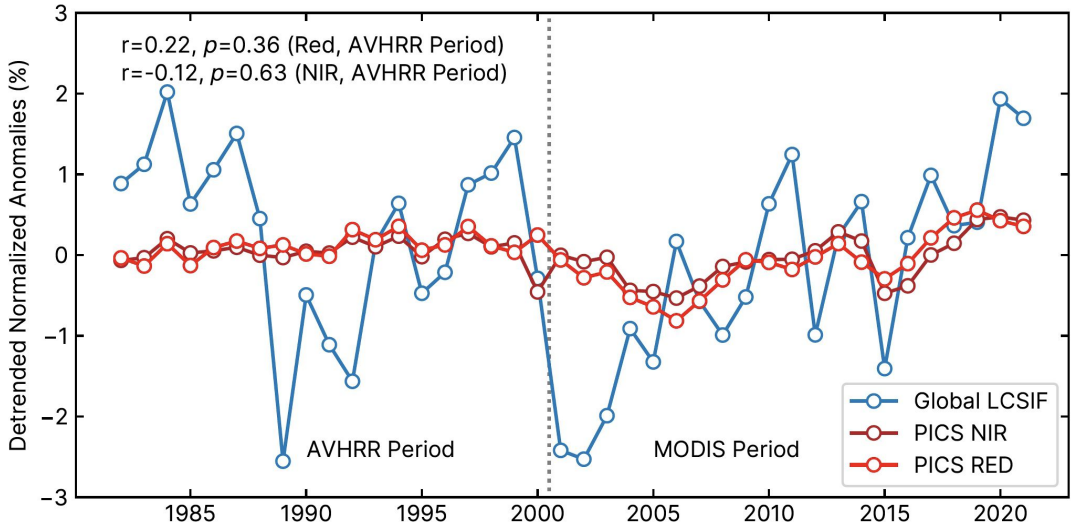


$$\overline{F_s} = F_s/\cos(SZA(t_0)) \cdot \int_{t=t_0-12h}^{t=t_0+12h} \cos\big(SZA(t)\big)\, dt$$

LCSIF Model Performance

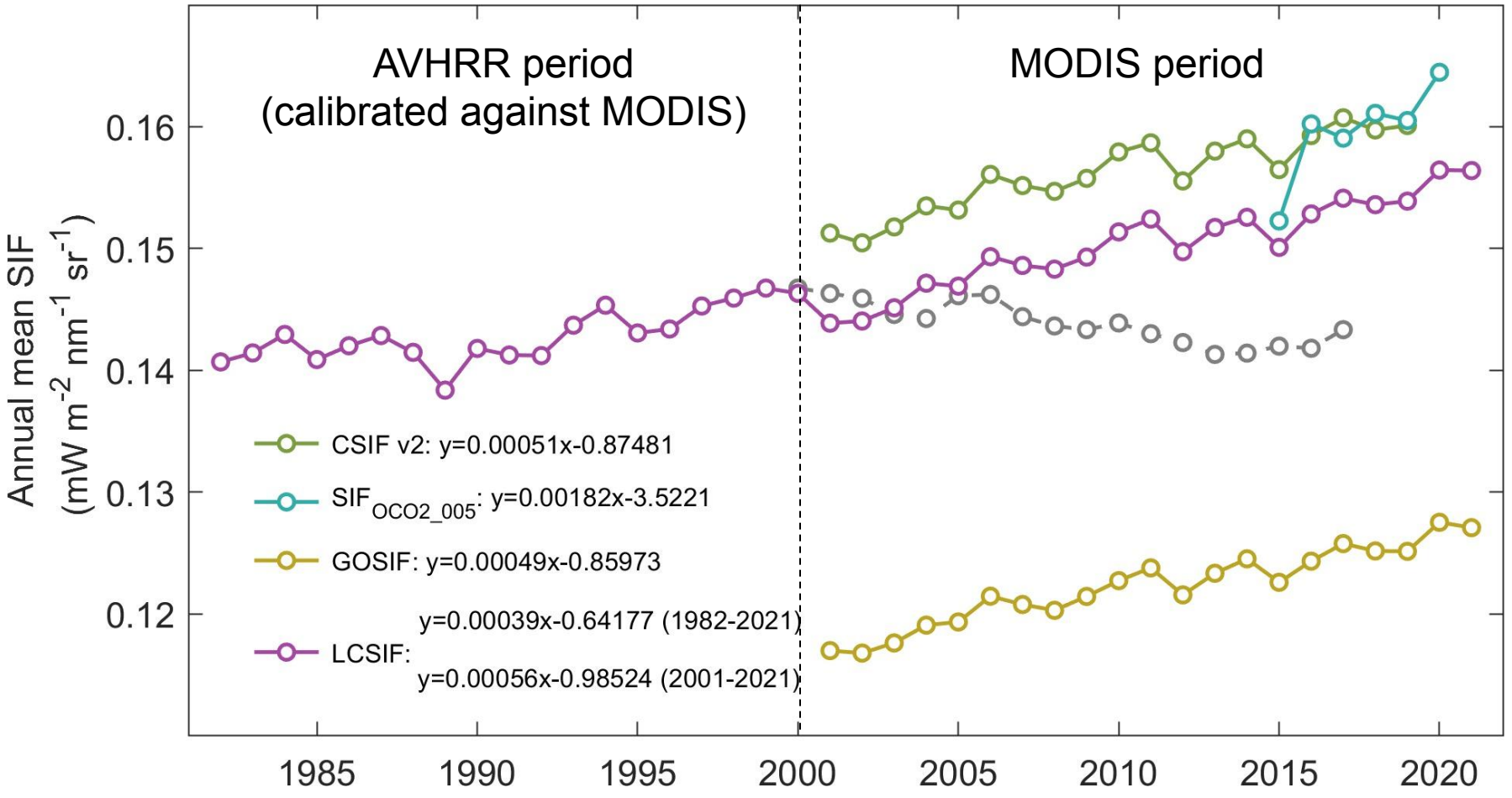


Validation on held-out OCO-2 SIF observations

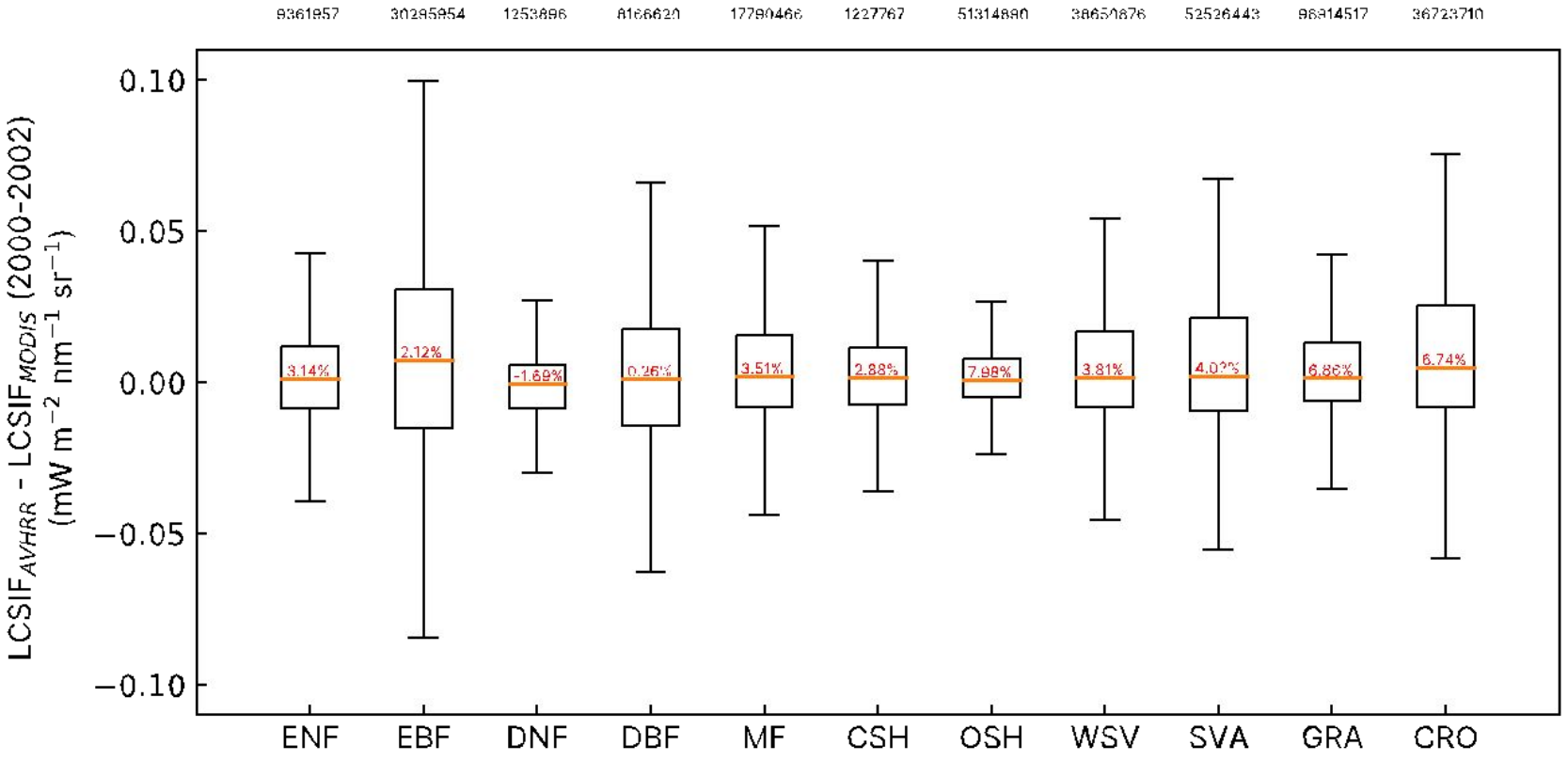


Validation against vegetation free pseudo-invariant calibration sites (PICS)

Global comparison with available OCO-2-based SIF products



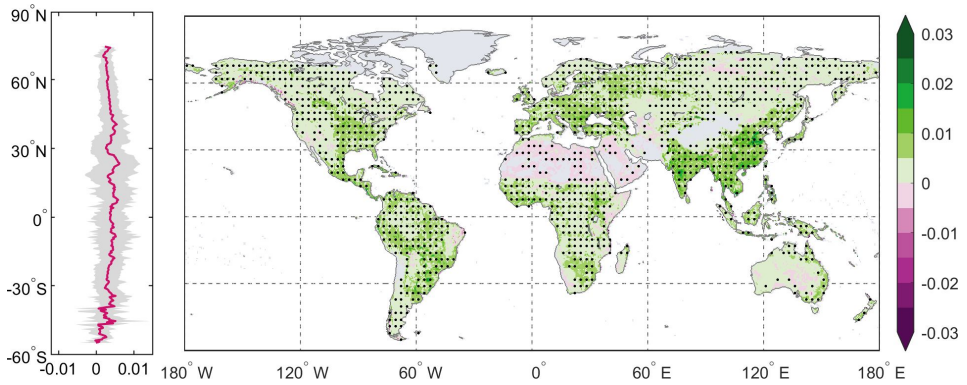
Difference between MODIS and calibrated AVHRR-based SIF, 2000-2002



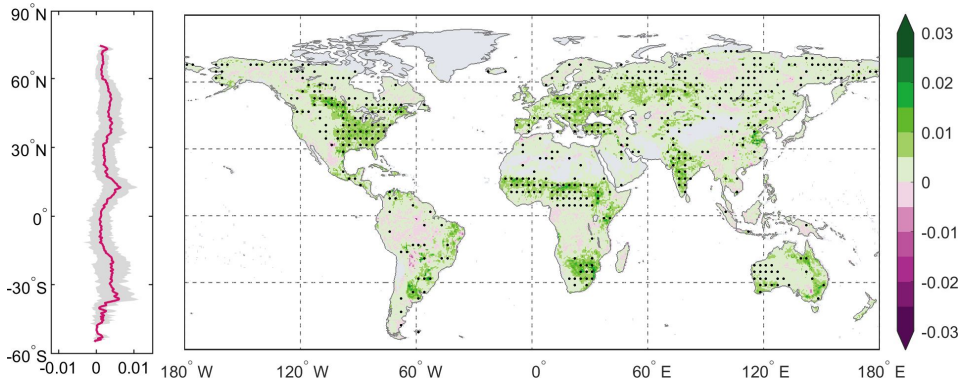
The number at the top indicates the number of aggregated samples at 0.05°. The number in red is the percentage difference between the mean value of the SIF predictions using either MODIS or calibrated AVHRR reflectance as input between 2000-2002, grouped by land cover type.

Global patterns of SIF trend (unit: mW m^{-2} nm^{-1} sr^{-1})

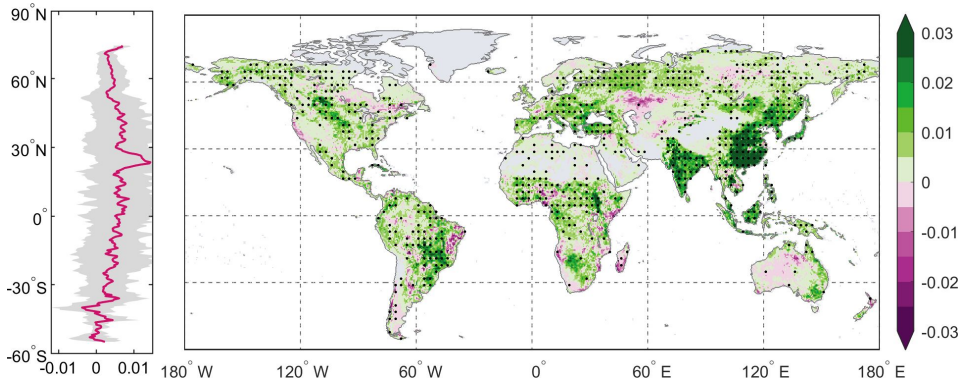
1982-2021



1982-2000

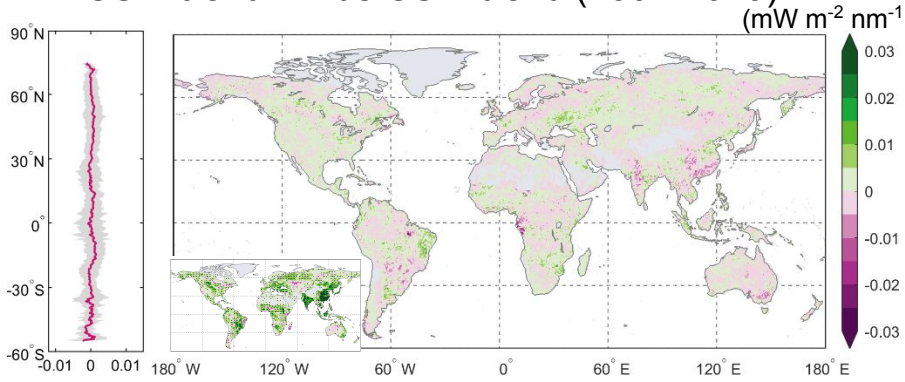


2001-2021

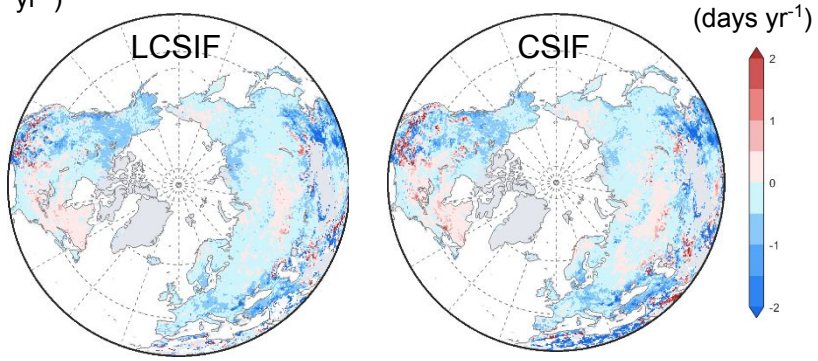


Comparison with four-band-based CSIF product

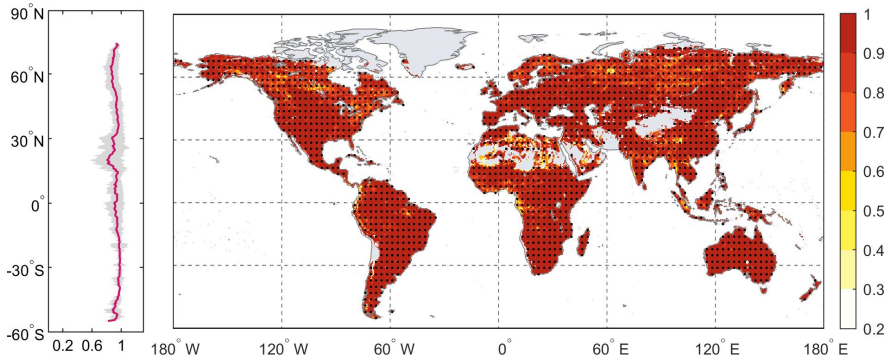
LCSIF trend minus CSIF trend (2001-2019)



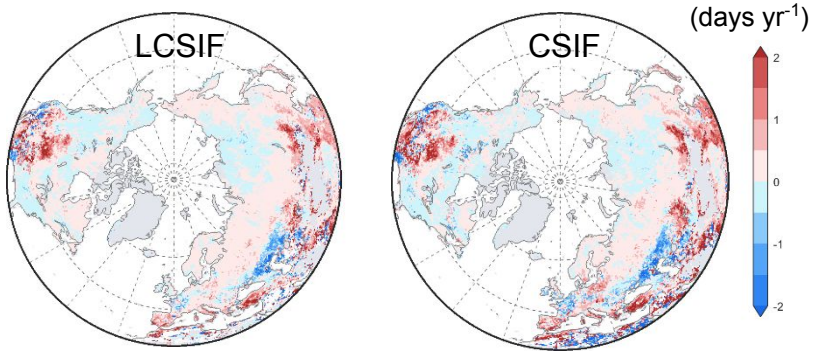
SOS trend (2001-2019)



r (LCSIF, CSIF)

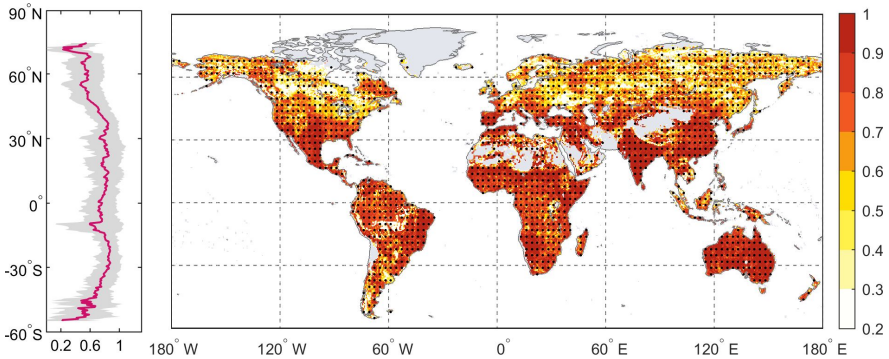


EOS trend (2001-2019)

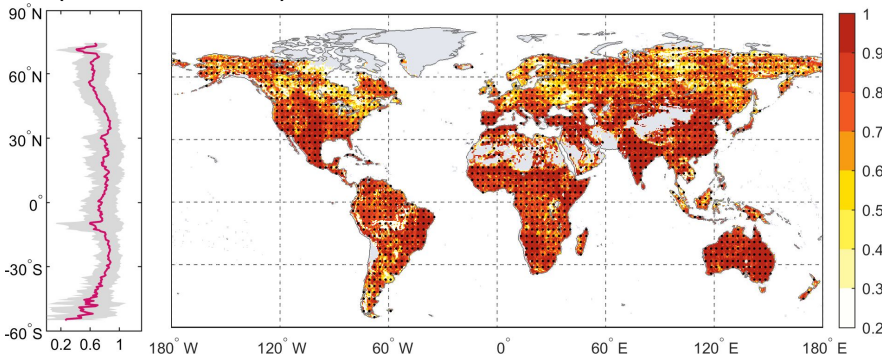


Comparison with commonly used VIs (red and nir as input)

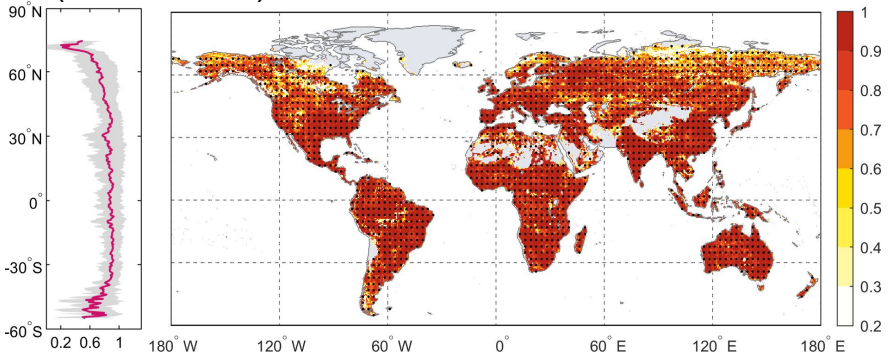
r (LCSIF, NDVI)



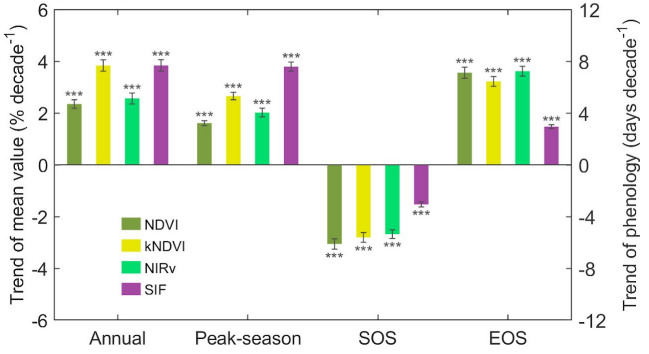
r (LCSIF, kNDVI)



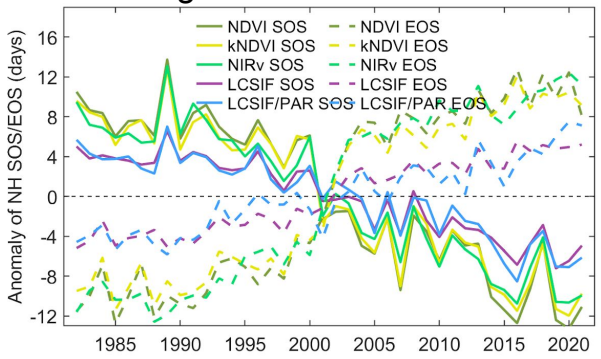
r (LCSIF, NIRv)



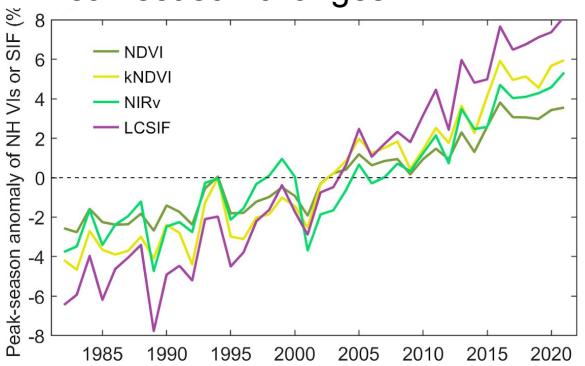
Long-term trends



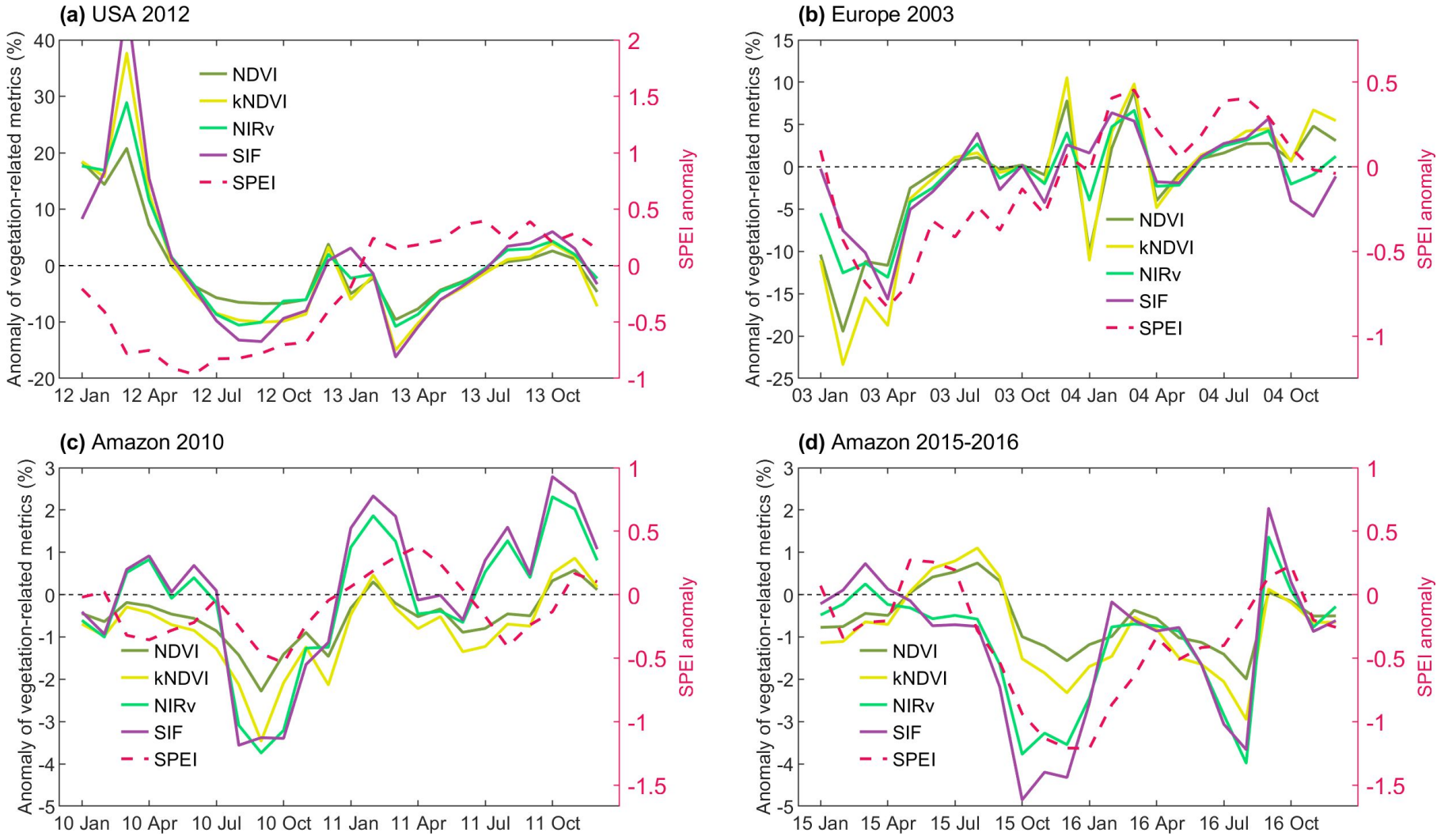
Phenological shifts



Peak-season changes



Comparison of ecosystem responses to drought events



Accessing LCSIF Data and Usage Notes

- We provide biweekly calibrated Red + NIR reflectance (LCREF) and SIF product (clear-sky instantaneous + clear-sky daily averaged) from 1982-2021 at 0.05º spatial resolution.

- The version 1 of the data is available for internal usage, and a formal version will become publicly available in May 2023.

- LCREF_v1 and LCSIF_v1 are now available for download upon request. To use LCSIF data, send an email to jf3423@columbia.edu with the email address associated with your Google account, and we will add you to a Google Drive folder within 24 hours. We will also add you to an email list for notifications of future updates to this dataset.

- Code used to calibrate and generate the data will be available once we submit the manuscript.

- **This LCSIF product could be potentially used to:**
  (1) assess long-term vegetation productivity responses to climate, CO_2 and LUCC.
  (2) benchmark representation of photosynthesis-related processes in Earth system models.

Key Takeaways

- We generated a long-term reflectance product by calibrating AVHRR against MODIS using a **combined linear + ML approach**.
- The **two-band algorithm** used in LCSIF has comparable prediction accuracy compared with the four-band algorithm in CSIF.
- The **temporal trend, IAV, phenology shift, and drought response** of LCSIF were generally **consistent** with that of CSIF.
- LCSIF demonstrated a **larger "greening" trend** compared with VIs, but it showed a **smaller phenology shift** in northern terrestrial ecosystems than VIs between 1982-2020.
- Further validations can focus on remaining **spurious trends** at PICS and comparing LCSIF with **independent observations** (e.g. VOD) .

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Thank You!

Questions & Suggestions Welcomed!