# Convergences and divergences between data-driven GPP estimates and high-resolution SIF measurements across vegetation and climatic gradients

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Estimating global GPP

- Gross Primary Production (GPP) estimation vital to carbon cycle estimations

- FLUXCOM* project scales up data from FLUXNET fluxtowers, using meteo and RS data to provide a global GPP estimate

- Significant uncertainty in the FLUXCOM estimates remains

http://fluxcom.org/EF-Products/

Photosynthesis

GPP → **Respiration**

Biomass

Machine Learning Methods

Global Meteorological Data

Global Carbon and Energy Fluxes

Satellite Earth Observation

FLUXNET In-situ Observation

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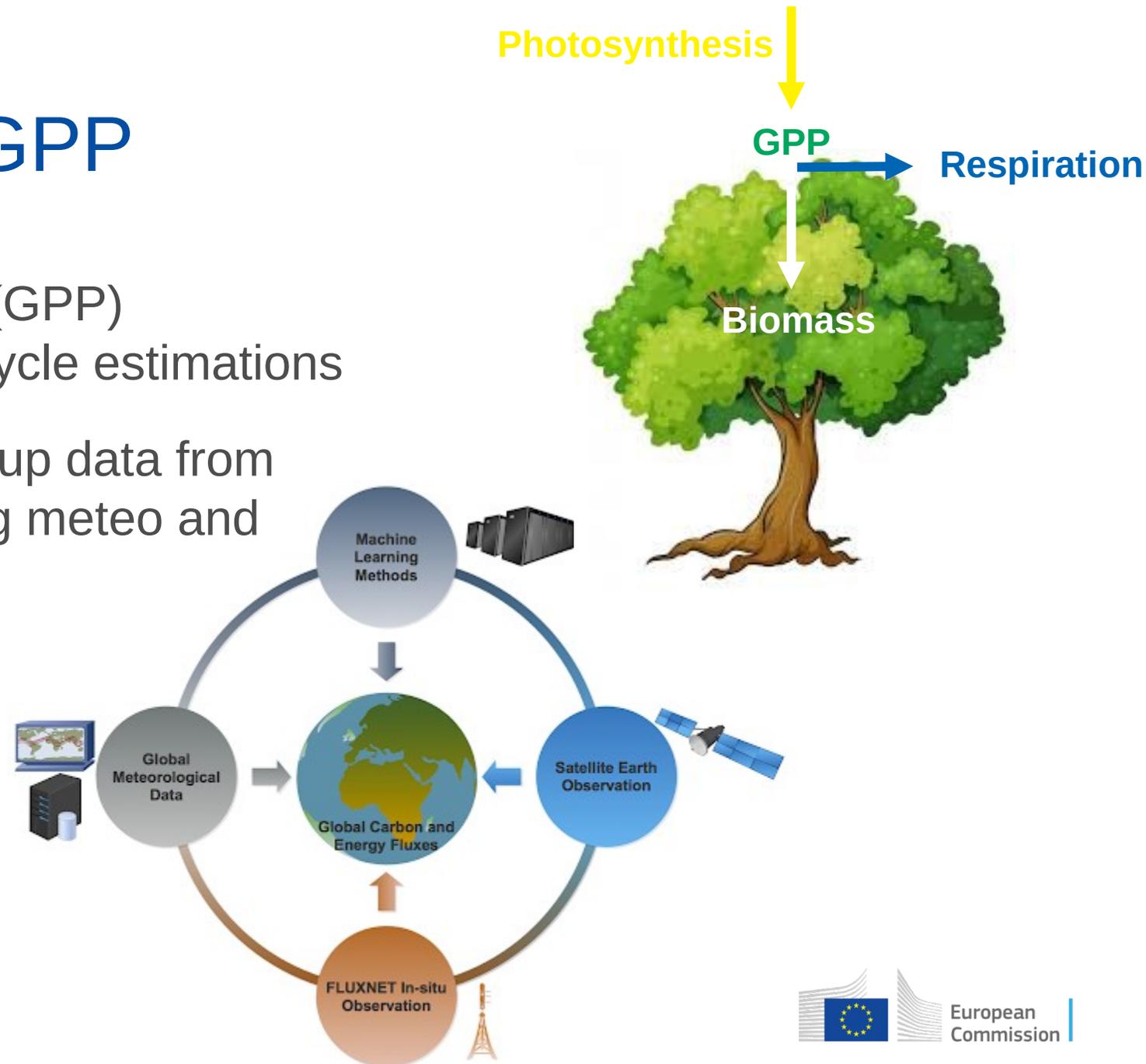
Solar Induced Fluorescence (SIF)

- Excited chlorophyll dissipates absorbed energy via photosynthesis, heat and fluorescence

- SIF can be used as an indicator of photosynthetic activity at different scales, including via remote sensing (RS)

- Relationship between SIF and GPP an area of active research

NASA
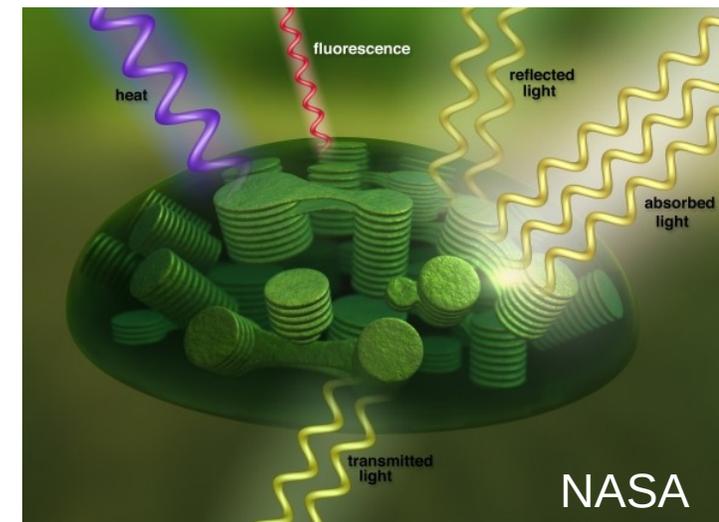
Downscaled SIF

- No dedicated satellite currently measuring SIF (FLEX in 2022)

- Satellites capable of retrieving SIF suffer from a mixture of: course resolution, sparse sampling, short data archive

- We can improve resolution, e.g. GOME-2 0.5° SIF→ dowscaled via Duveiller & Cescatti* method → 0.05° SIF

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* http://www. sciencedirect.com/science/article/pii/S0034425716301936
* https://www.earth-syst-sci-data-discuss.net/essd-2019-121/

GOME-2

[*SIF retrieval*]

Downscaling

MODIS

OCO-2

*Validation*

Inter-comparison

TROPOMI
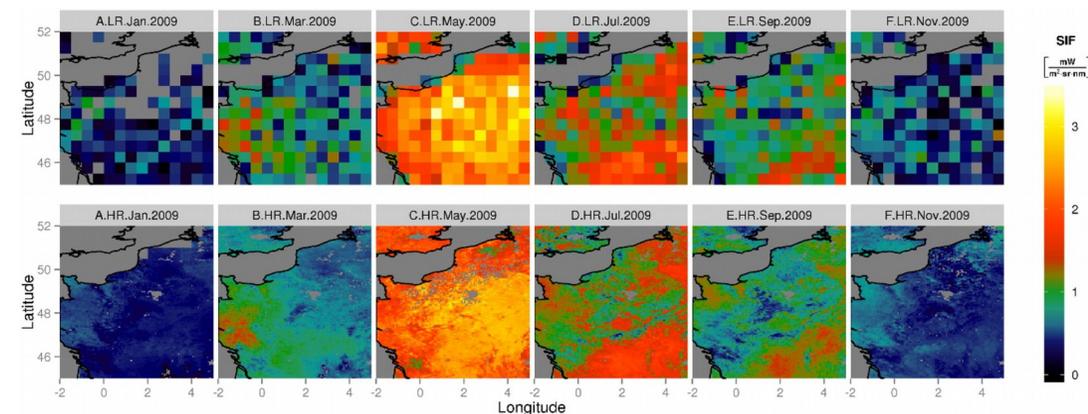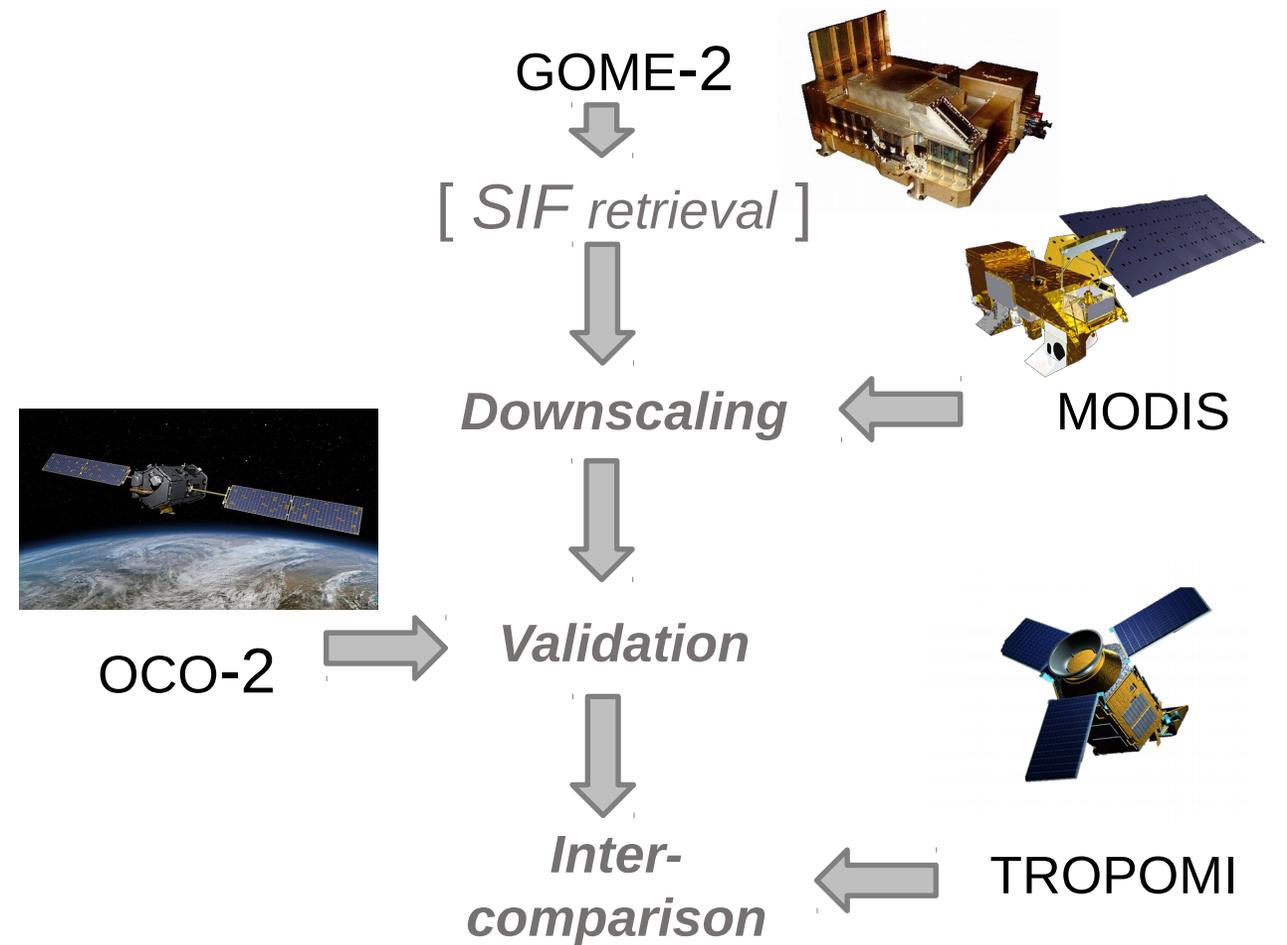
Downscaled SIF & GPP

- How can a contiguous, high-resolution, remotely sensed, long-archive SIF dataset improve our understanding the relationship with GPP?

- Contiguous:
  Investigate at a global scale

- High-resolution:
  Investigate in differing plant types

- Remotely-sensed: GPP is modelled. SIF is a real-time, observed proxy

- Long-archive:
  Investigate temporal trends & averaged spatial relationship

Mean growing season values between 2007-2014
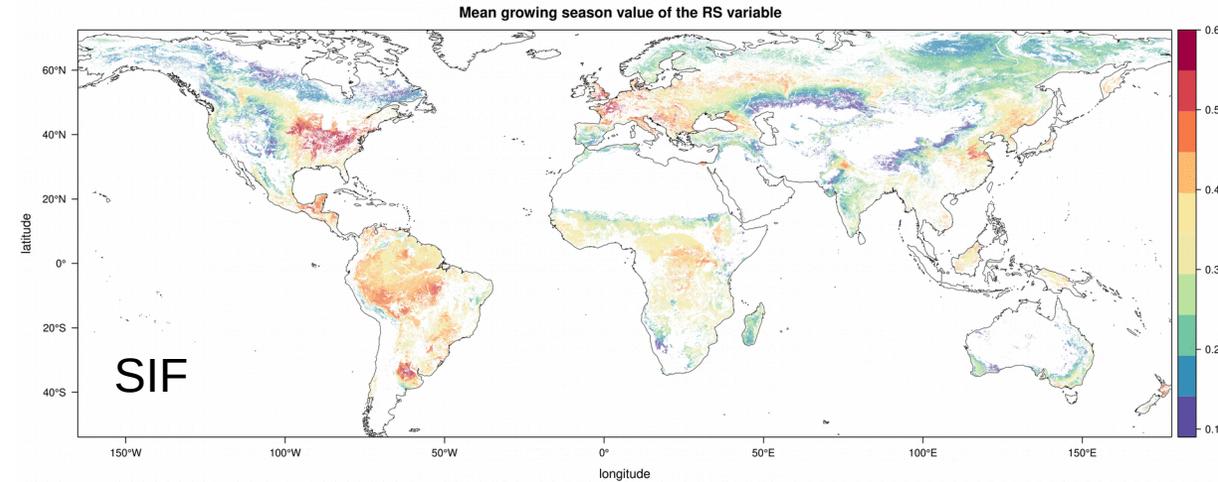
downscaled J. Joiner et al, 2013 retrieval: https://www.atmos-meas-tech.net/6/2803/2013/
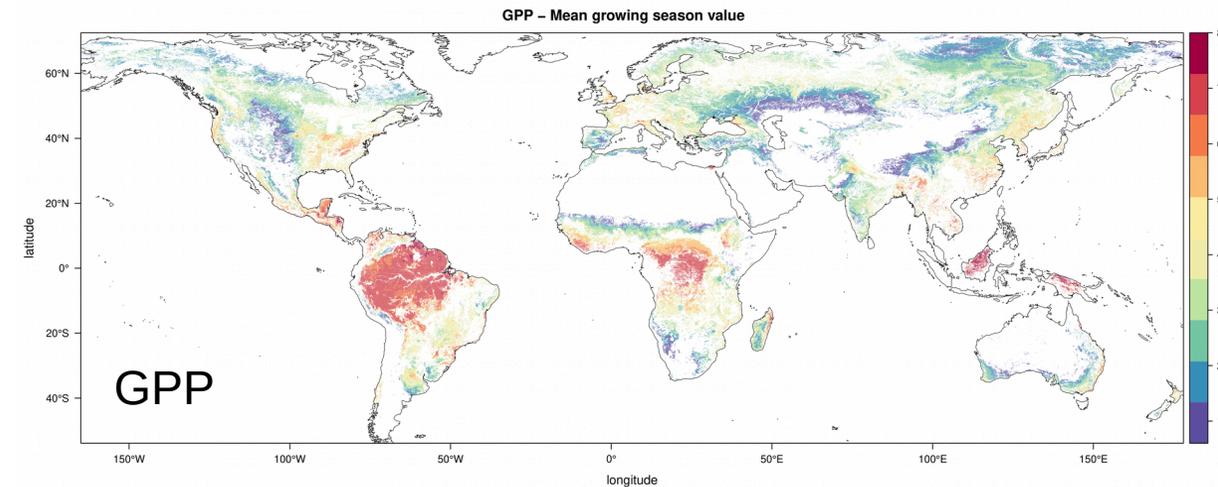
Downscaled SIF – FLUXCOM GPP relationships

- Spatial correlation between maximum SIF and GPP

- Spatial correlation between mean SIF & GPP

- Temporal correlation between SIF and GPP during the growing period

- Temporal correlation between mean growing period SIF and GPP between years

- Temporal correlation between maximum growing period SIF and GPP between years

- Mean: average growing seasons statistics
  Max: maximum photosynthetic potential
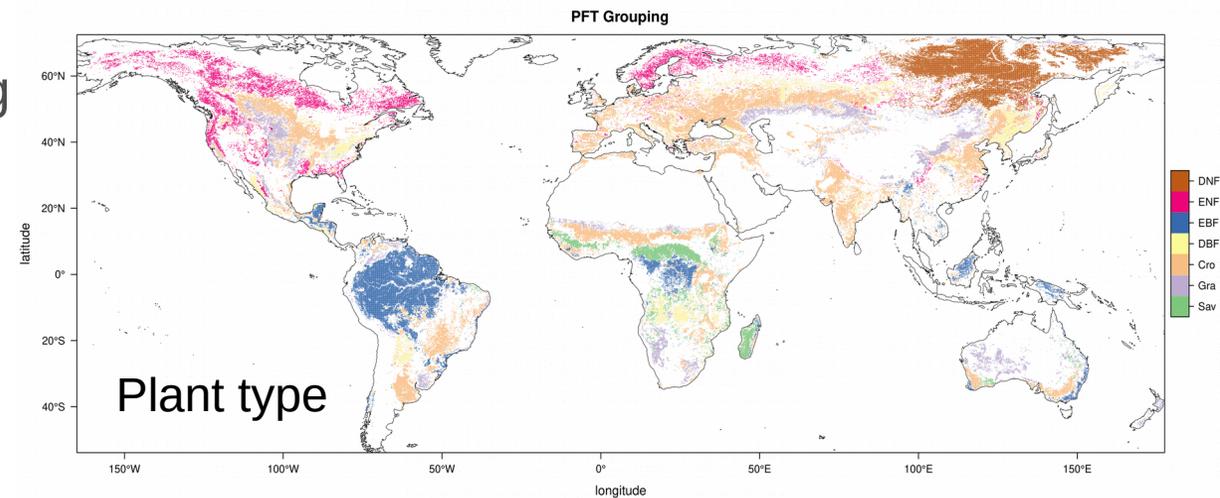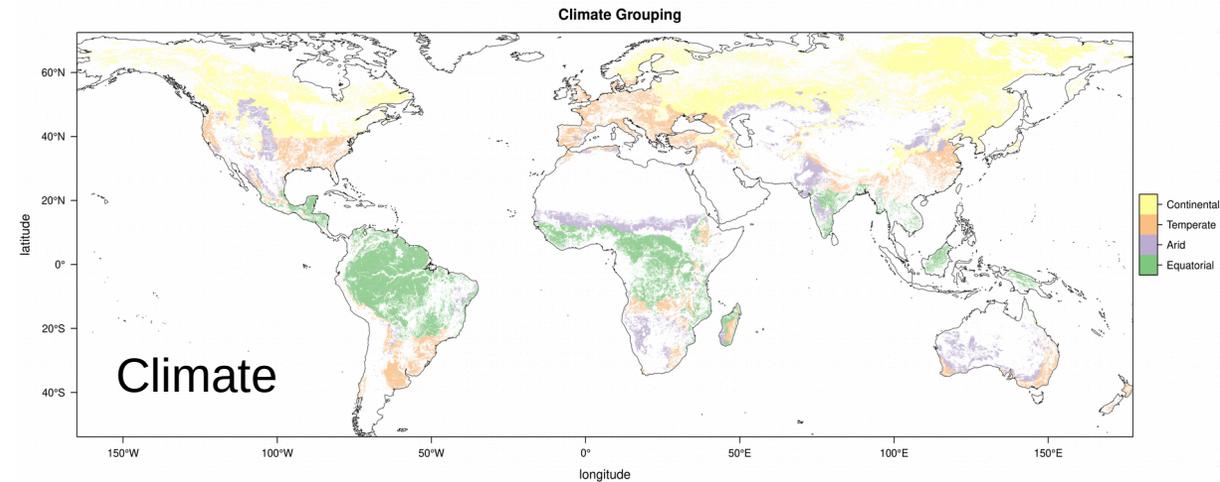
Climate

Plant type

Spatial relationship between SIF and GPP and breakdown by climate and plant type

ALL

$y = -0.38 + 13 \cdot x, \ r^2 = 0.573$
$RMSE = 1.2$

Mean annual GPP

Mean annual SIF
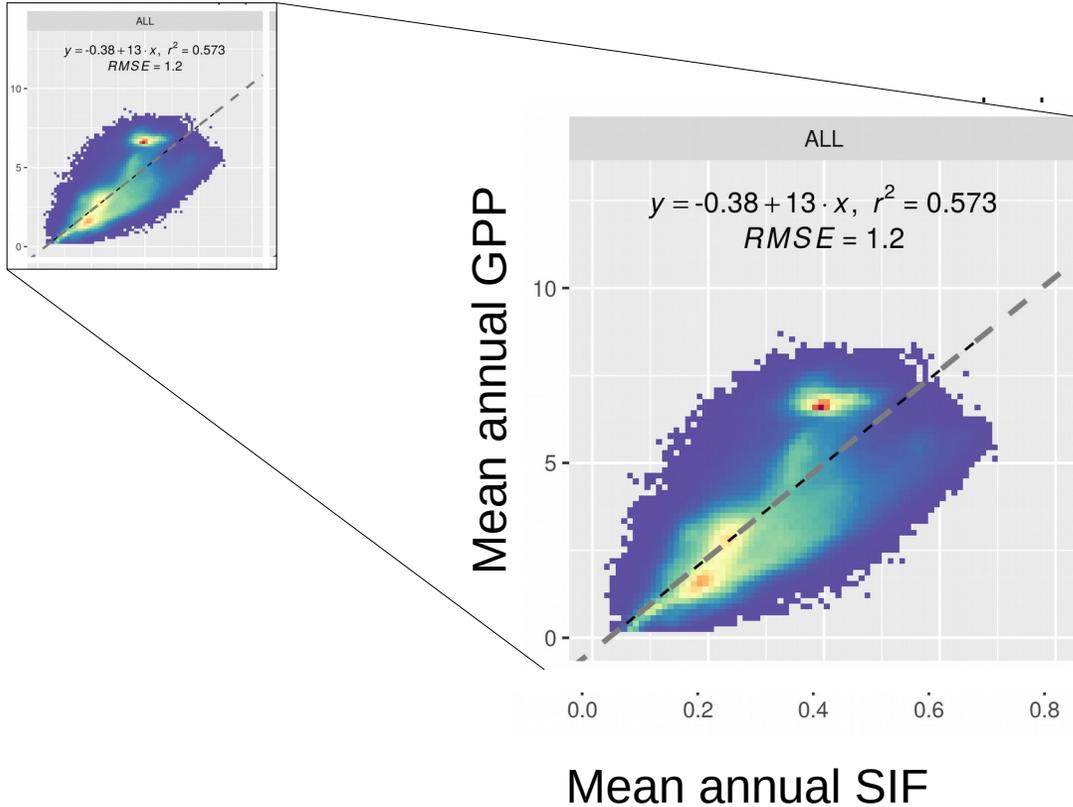
- Global spatial SIF-GPP relationship

- No breakdown by climate/vegetation

- Apparent substructure and features
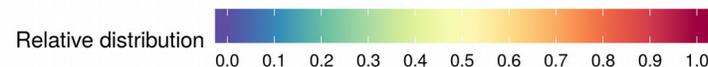
Relative distribution

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

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Spatial relationship between SIF and GPP and breakdown by climate and plant type

Mean annual GPP

SIFJJ mean Vs GPP mean per pixel for 1st GS of year

ALL — $y = -0.38 + 13 \cdot x, \ r^2 = 0.573$, $RMSE = 1.2$

EQUATORIAL — $y = 0.0088 + 15 \cdot x, \ r^2 = 0.448$, $RMSE = 1$

ARID — $y = -0.44 + 11 \cdot x, \ r^2 = 0.694$, $RMSE = 0.65$

TEMPERATE — $y = 1.1 + 7.5 \cdot x, \ r^2 = 0.355$, $RMSE = 1$

CONTINENTAL — $y = 0.86 + 6.9 \cdot x, \ r^2 = 0.482$, $RMSE = 0.7$
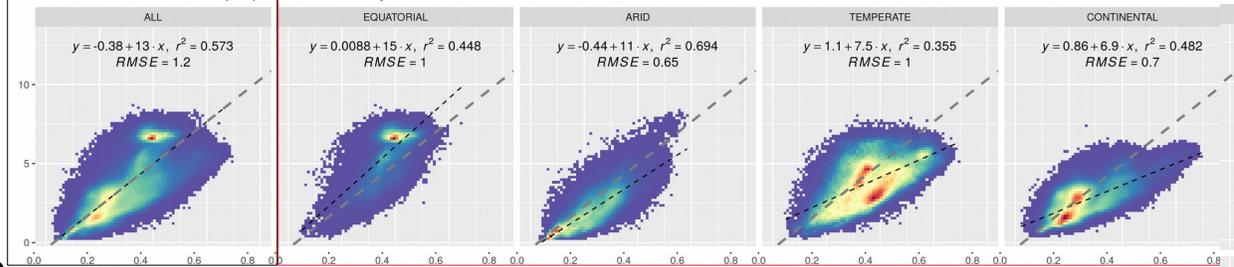
Equatorial   Arid   Temperate   Continental

Savannah — $y = -0.83 + 16 \cdot x, \ r^2 = 0.784$, $RMSE = 0.66$

Grassland — $y = -0.21 + 8.9 \cdot x, \ r^2 = 0.717$, $RMSE = 0.58$

Cropland — $y = 0.11 + 9.5 \cdot x, \ r^2 = 0.525$, $RMSE = 0.86$

ALL — $y = 4.7 + 4.7 \cdot x, \ r^2 = 0.135$, $RMSE = 0.61$

Evergreen Broad-leaf (EBF)

SAV — $y = 2.9 + 4.2 \cdot x, \ r^2 = 0.151$, $RMSE = 0.77$

Deciduous Broad-leaf (DBF)

GRA — $y = 0.59 + 12 \cdot x, \ r^2 = 0.612$, $RMSE = 0.59$

Evergreen Needle-leaf (ENF)

CRO — $y = -0.38 + 12 \cdot x, \ r^2 = 0.472$, $RMSE = 0.5$

Deciduous Needle-leaf (DNF)

- Can break down between climates (top)

- Can break down by vegetation cover (sides)
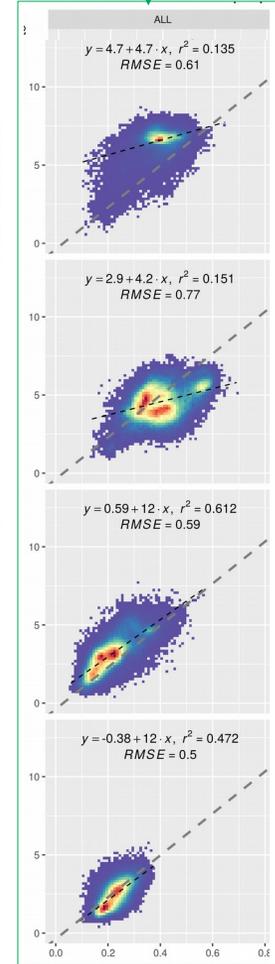
- This separates *some* of the substructure

- High resolution enables breakdown by both...

Mean annual SIF

Mean annual SIF

Relative distribution

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

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Spatial relationship between SIF and GPP and breakdown by climate and plant type
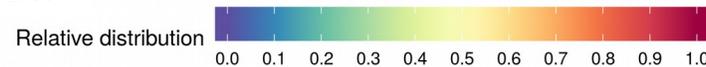
Spatial correlation

- Global spatial correlation between SIF & GPP re-expressed via map

- Each pixel shows: Above (below): spatial correlation (taken from previous figure) between mean (max) SIF & mean (max) GPP during growing season [data taken 2007-2014]

- Notable lack of correlation in tropics and continental broad-leaf forests

Spatial correlation, r, between mean SIFJJ and GPP over the first growing season of the year [2007–2014]

Mean annual SIF vs mean annual GPP

Spatial correlation, r, between maximum SIFJJ and GPP over the first growing season of the year [2007–2014]

Max annual SIF vs max annual GPP
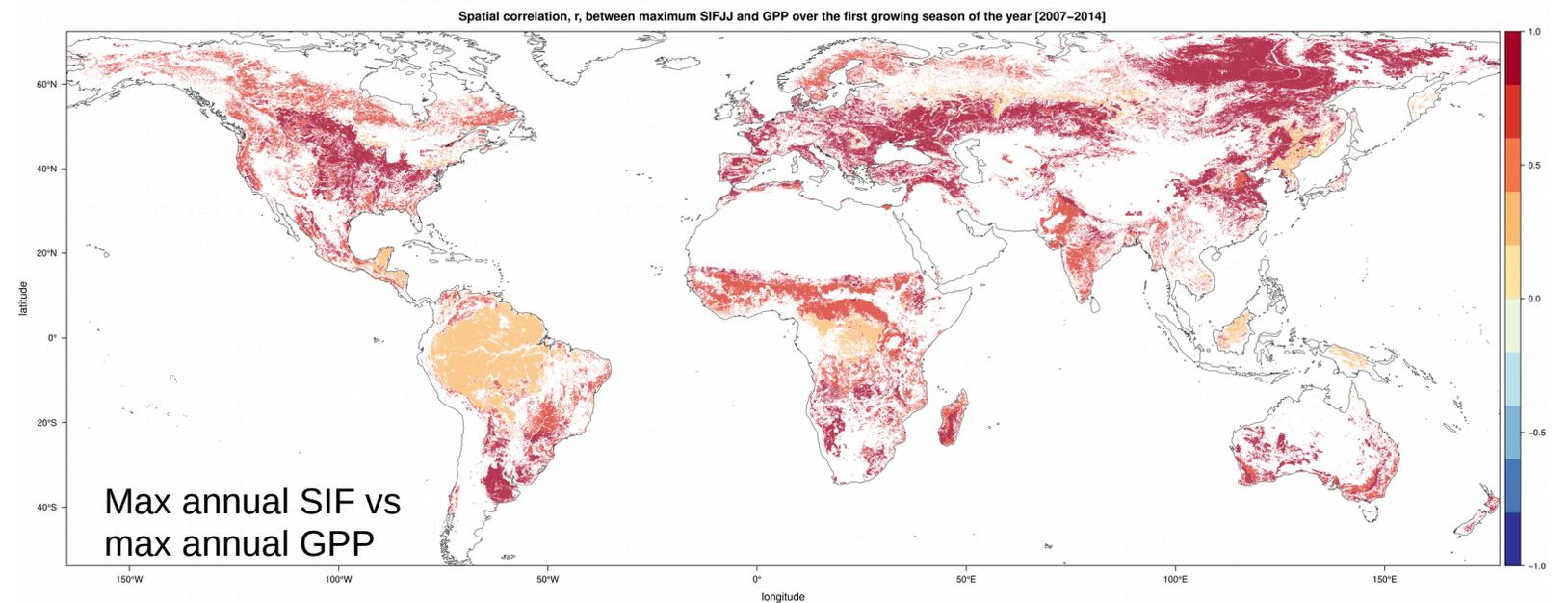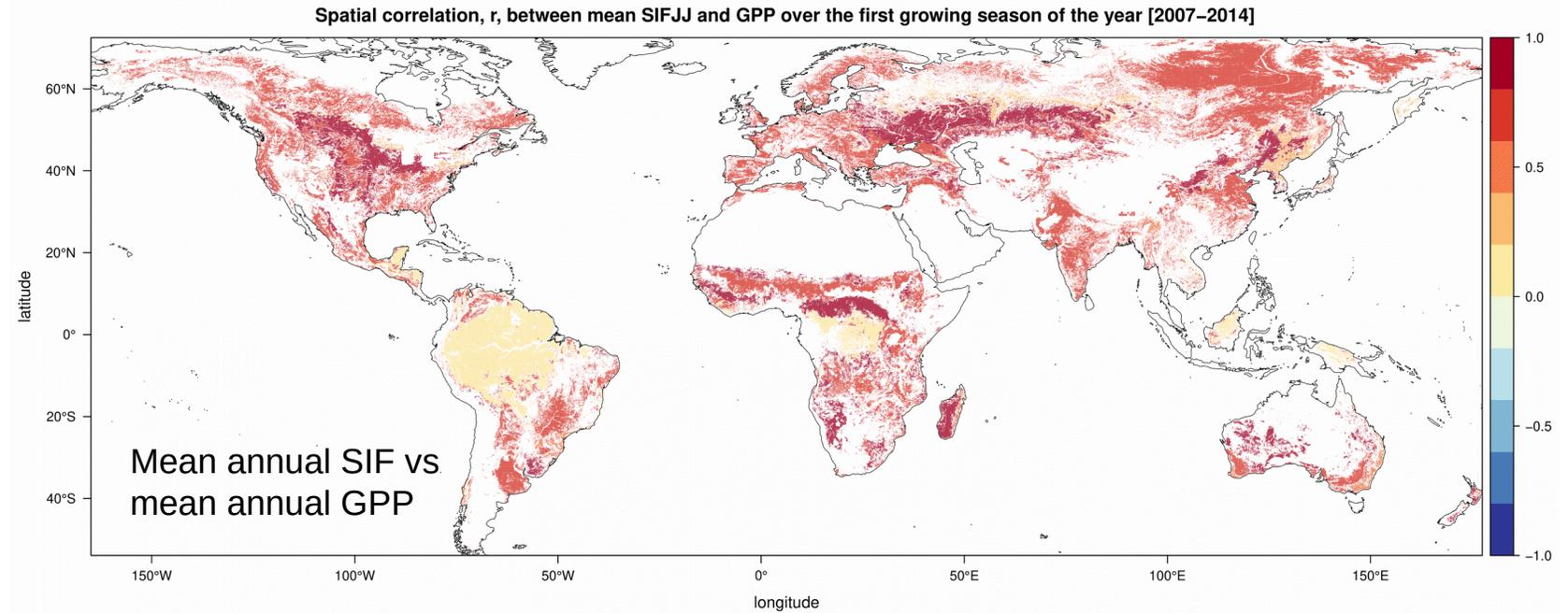
Temporal correlation: trend between years

- Repeat for inter-annual temporal correlation between SIF & GPP at each pixel

- Each pixel shows:
  Above (below): temporal correlation between mean (max) SIF & mean (max) GPP over the years 2007-2014

- Similar lack of correlation in tropics and some continental areas

Temporal correlation, r, between mean SIFJJ and GPP over the first growing season of the year [2007–2014]

Mean annual SIF vs mean annual GPP

Temporal correlation, r, between max SIFJJ and GPP over the first growing season of the year [2007–2014]

Max annual SIF vs max annual GPP
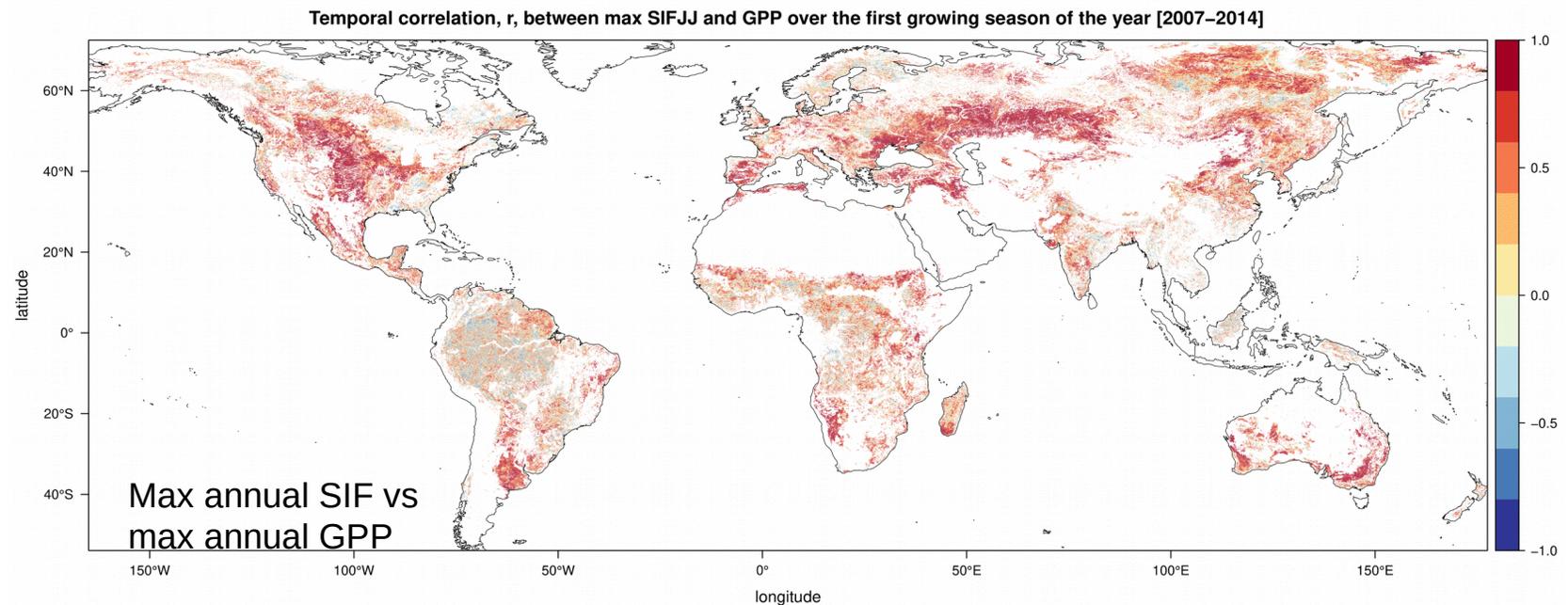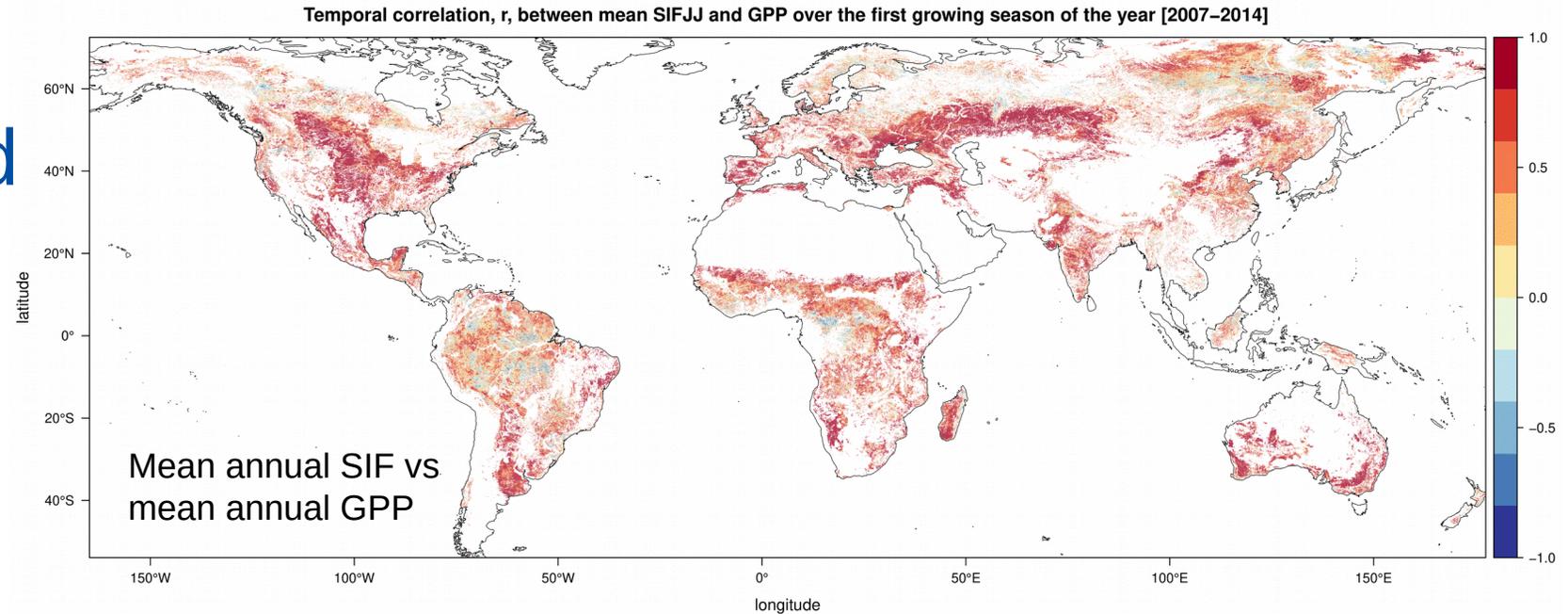
Temporal correlation: during growing season

- Repeat for intra-annual temporal correlation between SIF & GPP at each pixel

- Each pixel shows the correlation between SIF and GPP within a growing season [correlation at each pixel averaged over years 2007-2014]

- SIF and GPP out of step in the tropics

Temporal correlation, r, between SIFJJ and GPP within the first growing season of the year [2007–2014]
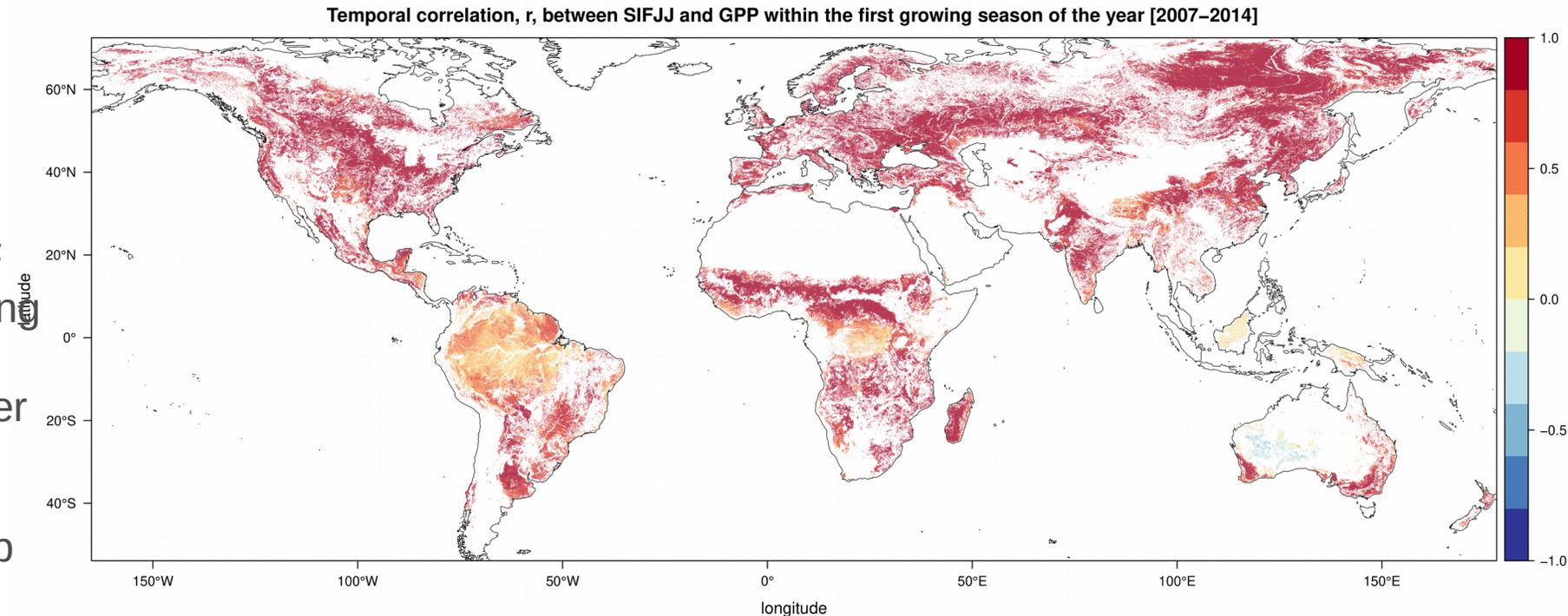
Spatio-temporal comparisons

- Correlation between SIF-GPP measurements highest within a growing period (red)

- Spatial correlations higher (blue/purple) than inter-annual trends (green/yellow)

- Spatial correlations higher for non-woody plants

- Significant areas of discrepancy in SIF-GPP (particularly equatorial broad-leaf forests)

- Paper out shortly (watch this space)
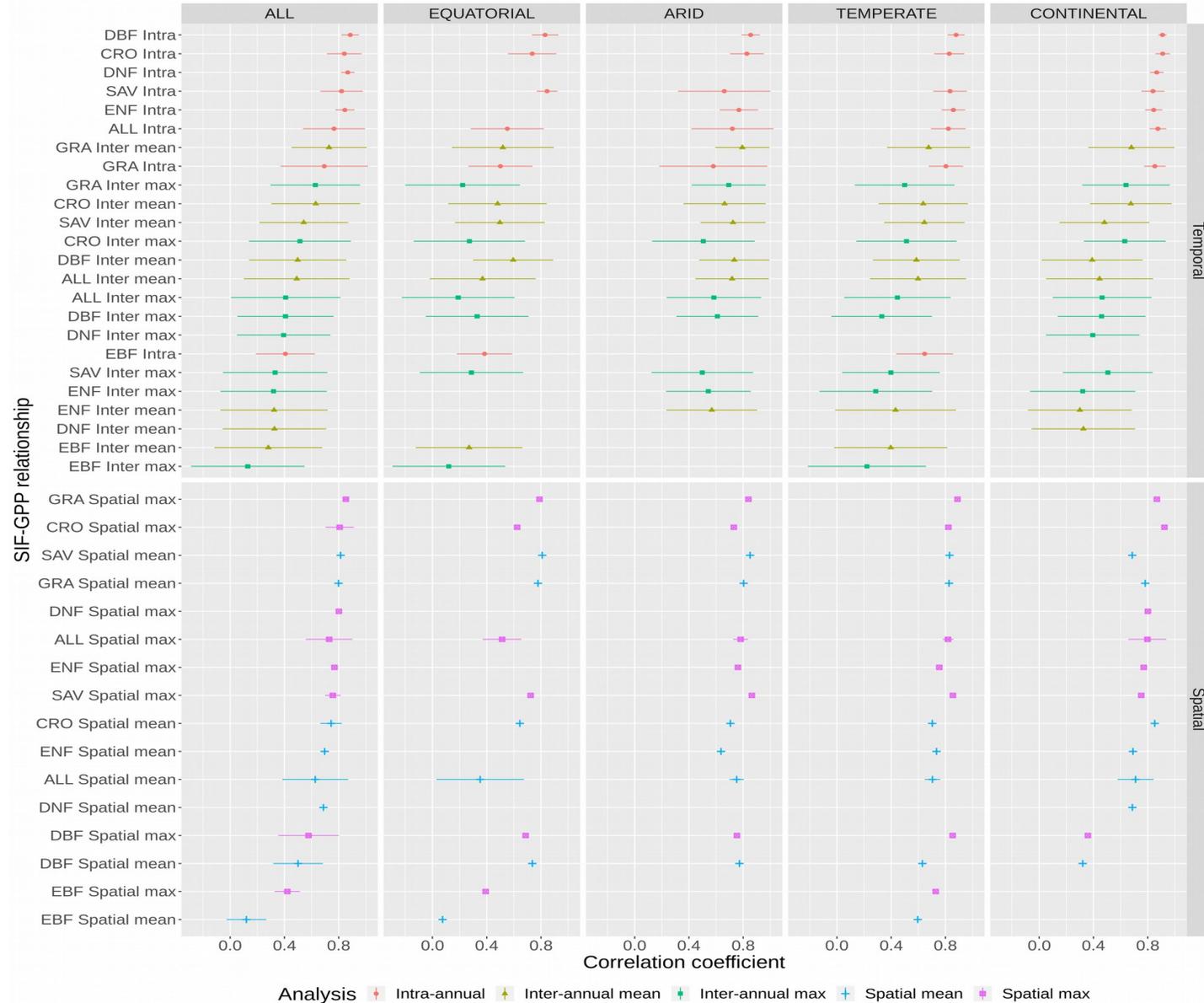
Figure B1. The correlation coefficient, r, for the temporal and spatial relationships between the downscaled SIF and FLUXCOM GPP. The r-value is determined between the SIF and the GPP over the years 2007-2014, and categorised by climate and plant cover. For the temporal analyses, the mean and standard deviation of the r-values across all pixels within a climate-vegetation category are shown. For the spatial analyses, each climate-vegetation category results in a single r-value, and in aggregated categories only the mean and standard deviation is shown.

SIF-GPP and climate

- Given that there is reasonably strong correlation between downscaled SIF and FLUXCOM GPP, can we observe climate stress remotely in the SIF data?

- Investigate the deviation in downscaled SIF and FLUXCOM GPP from the multi-year mean [2007-2015] in terms of the # standard deviations. Plot as a function of the deviations from the climatic mean (2001-2017)

- Ongoing study...

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SIF-GPP and climate

- Deviations of (2-week) GPP measurements between 2007-2015 in terms of the deviation from the climatic conditions (temperature and soil moisture)

- Observe many expected patterns: subtropics benefit from extra moisture; Continental regions benefit from temperature rises, etc.

- Can we detect these stresses remotely...
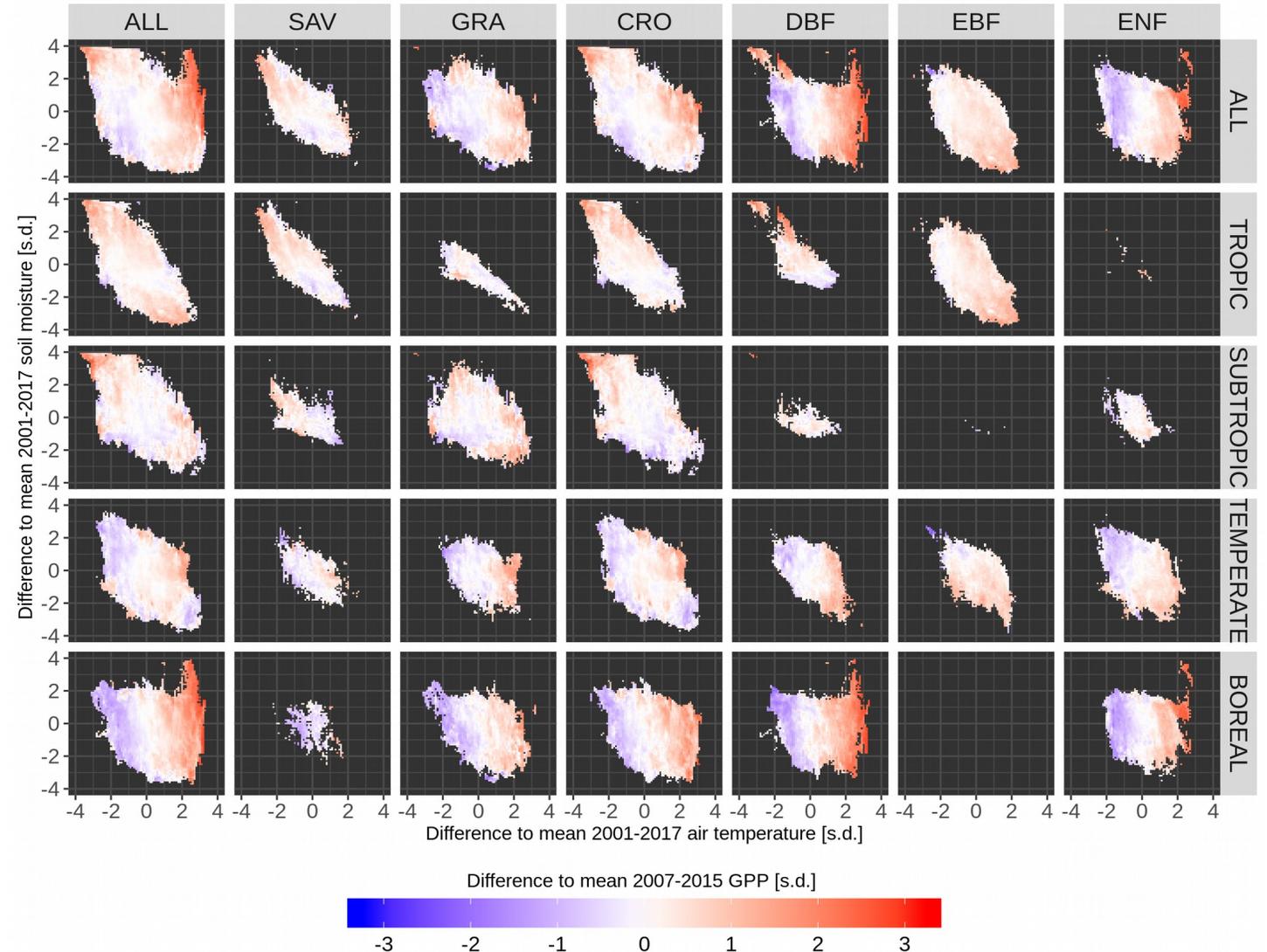
SIF-GPP and climate

- Deviations of (2-week) downscaled SIF measurements between 2007-2015 in terms of the deviation from the climatic conditions (temperature and soil moisture)

- Lower sensitivity to many of the expected patterns, but we can detect the stresses

- Analysis ongoing
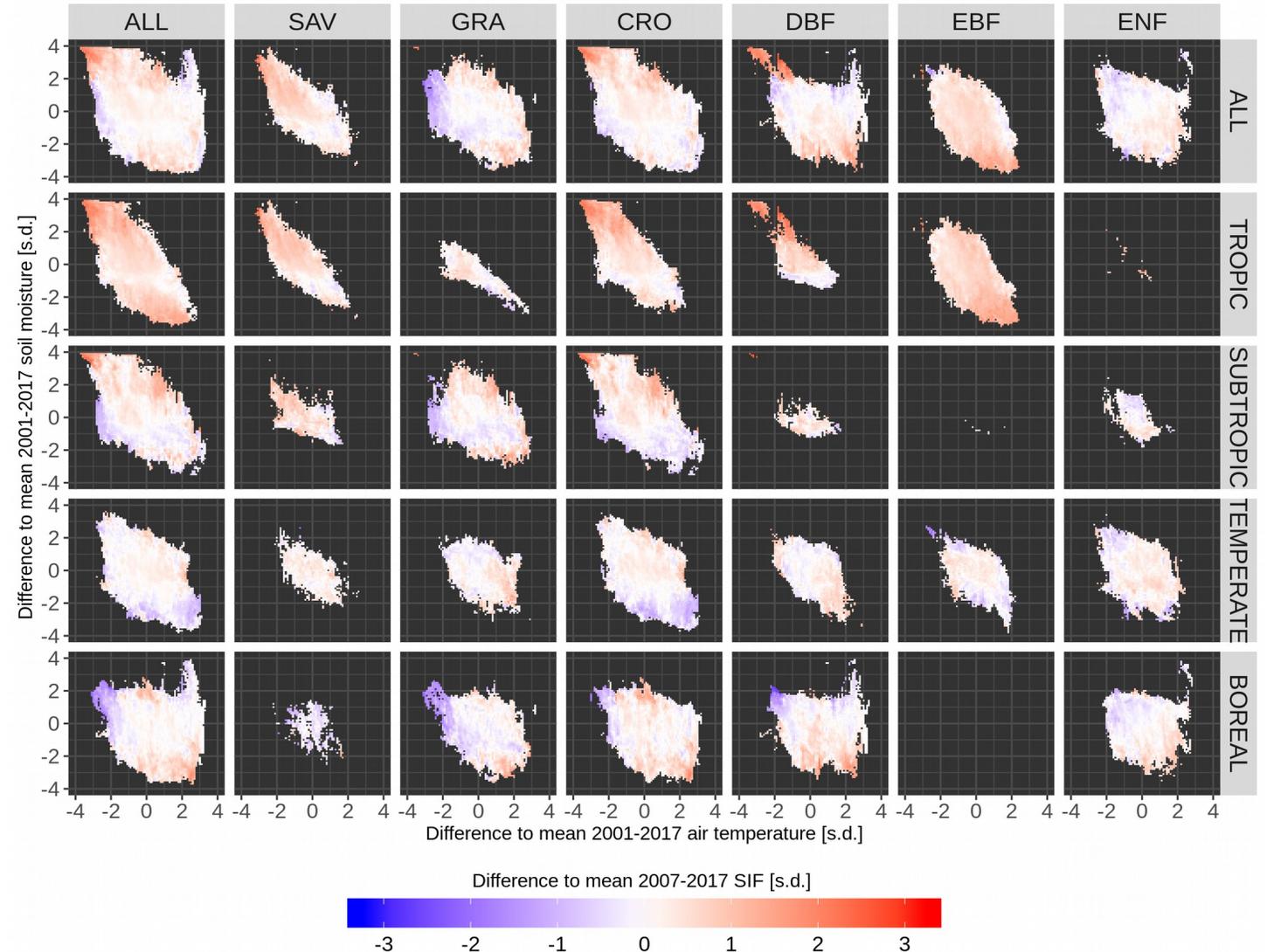
Conclusions

- Downscaled SIF serves as a useful proxy for GPP

- Using downscaled SIF we can explore limitations of the FLUXCOM GPP dataset (e.g. equatorial forests)

- The relatively fine resolution of the downscaled SIF enables a global exploration of the spatio-temporal relationship between SIF and GPP at a level that distinguishes between differing land cover types

- Slight flattening of the spatial GPP-SIF relationship at high values – could result from saturation in absorbed PAR

- Potential for downscaled SIF as an RS measurement of climatic stress

- Pre-print out soon – link will appear here!

Thank you

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# Selection requirements and data

- The same pixels are used in each of the spatial and temporal analyses (N=1.5m)

- The growing season is defined via the NASA Vegetation Index and Phenology, the CCI-LC defines the plant functional type, koppen-geiger defines the climate classification

- The following requirements
  – At least 10 instances of valid SIF satellite observations of the pixel within the growing season.
  – Less than 40% of the expected number of satellite observations within a growing season are missing or invalid.
  – The dominant plant functional type covers at least 75% of the pixel.
  – At least six years of valid measurements satisfying the requirements.
  – Only the first growing season of each year is considered in regions with multiple growing seasons.

Distribution of spatio-temporal correlations – categorised by climate-vegetation
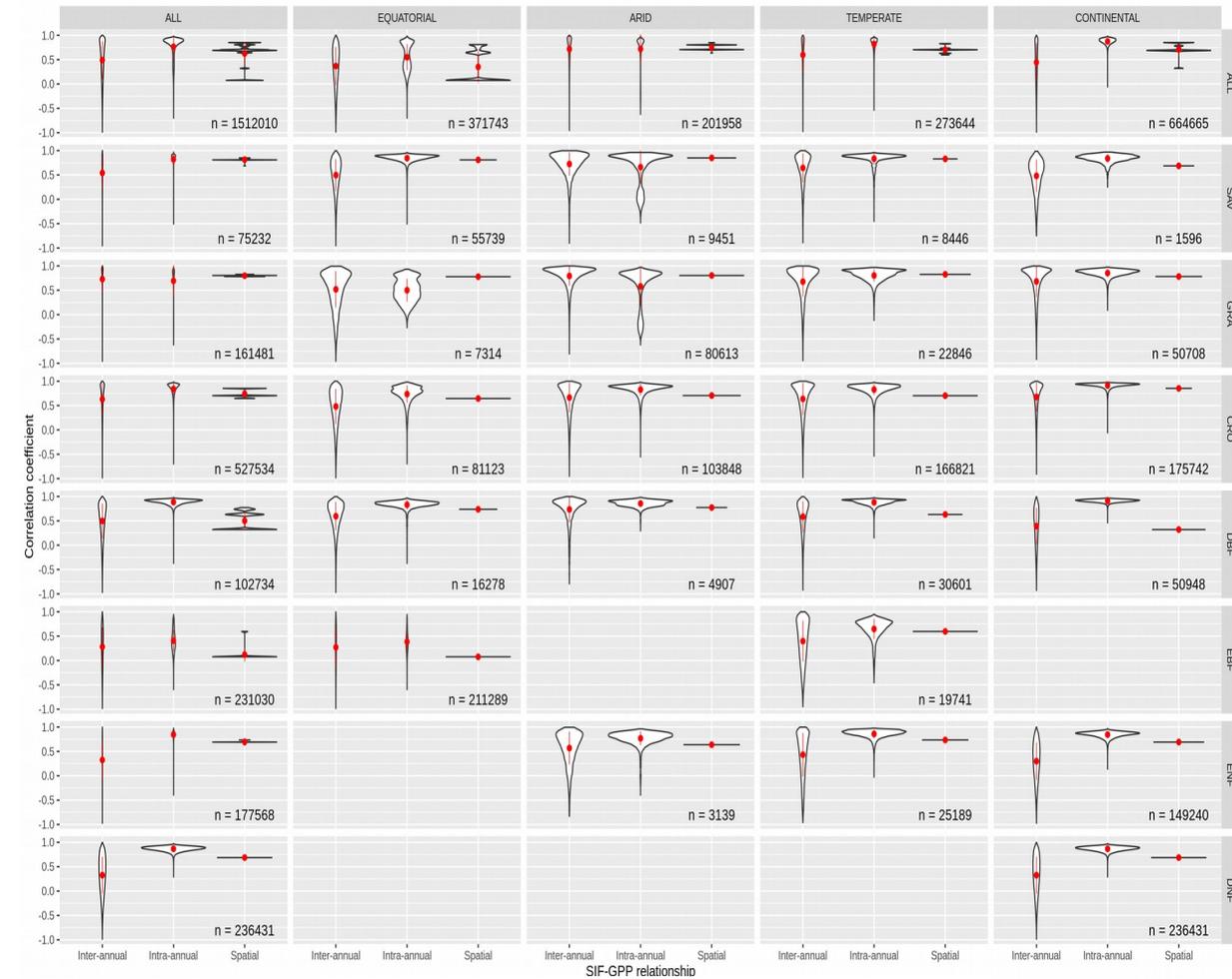
Mean SIF-GPP relationships

Max SIF-GPP relationships