Forward modelling of Solar Induced Fluorescence from JULES

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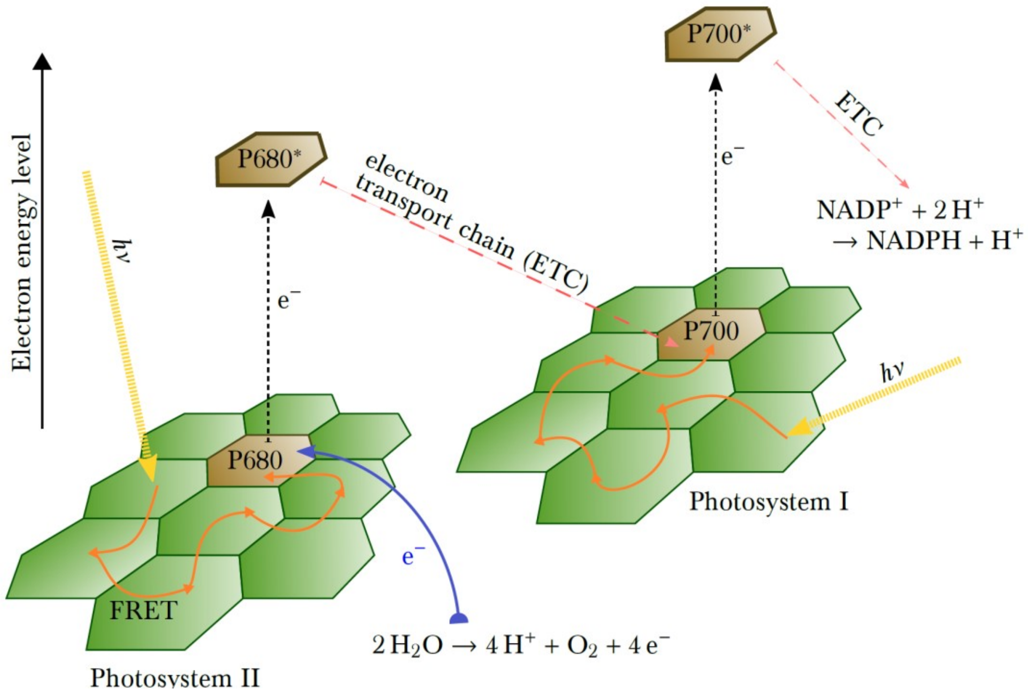
Why Solar Induced Fluorescence?

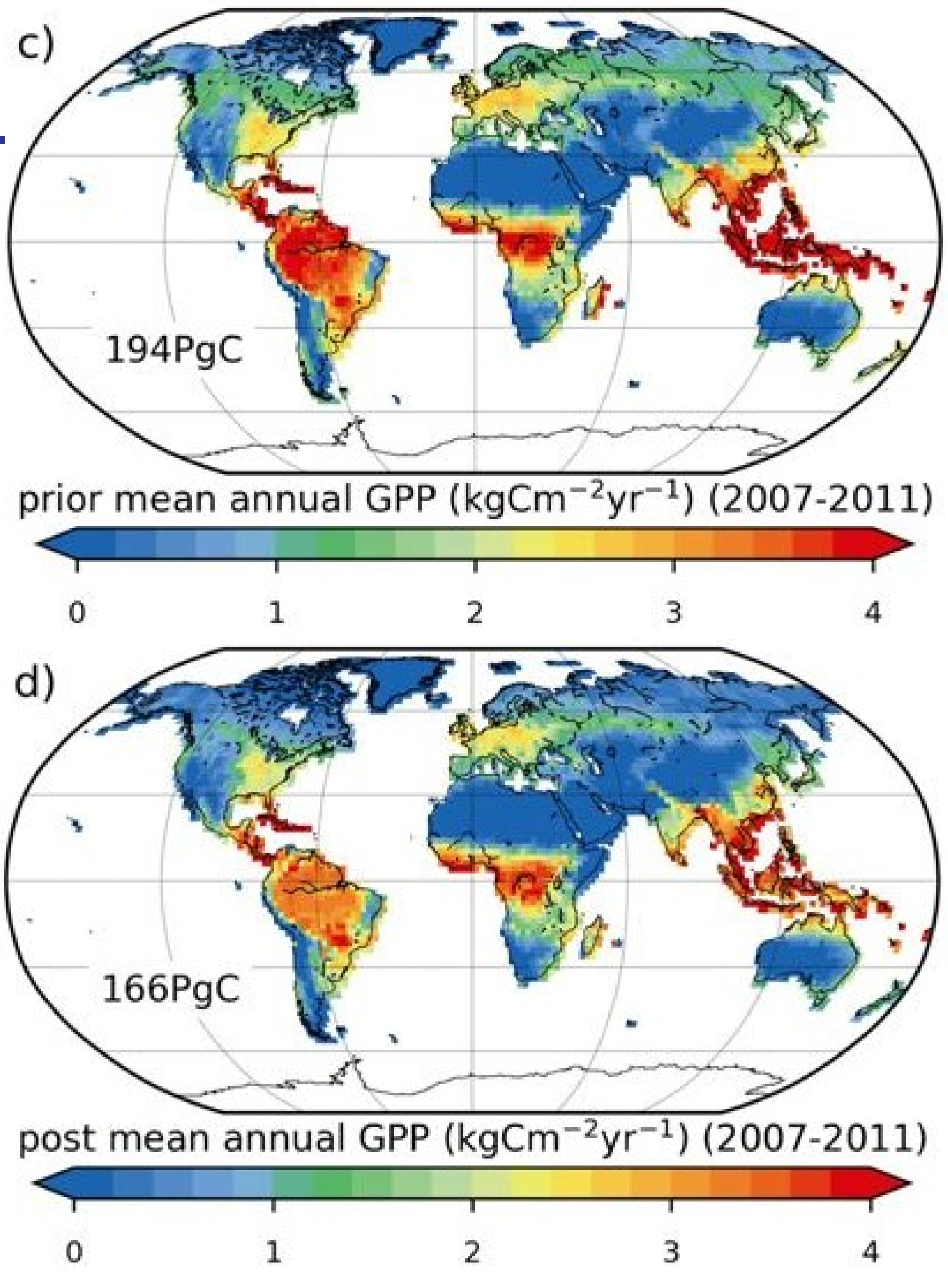
- SIF provides a potentially independent measure of the photosynthetic flux of carbon (GPP) at large scales.
- Understanding how GPP behaves in response to climate and elevated CO_2 is critical to understanding climate change and feedbacks with the carbon cycle.



SIF-model comparison strategy

Two options:

1. Assume simple SIF-GPP relationship
   a) Typically $GPP = k \times SIF$
   b) Generally relies on model assumptions to define k
2. Forward model SIF
   a) Can treat full physics problem
   b) Ensures model consistency
   c) Requires new model operators



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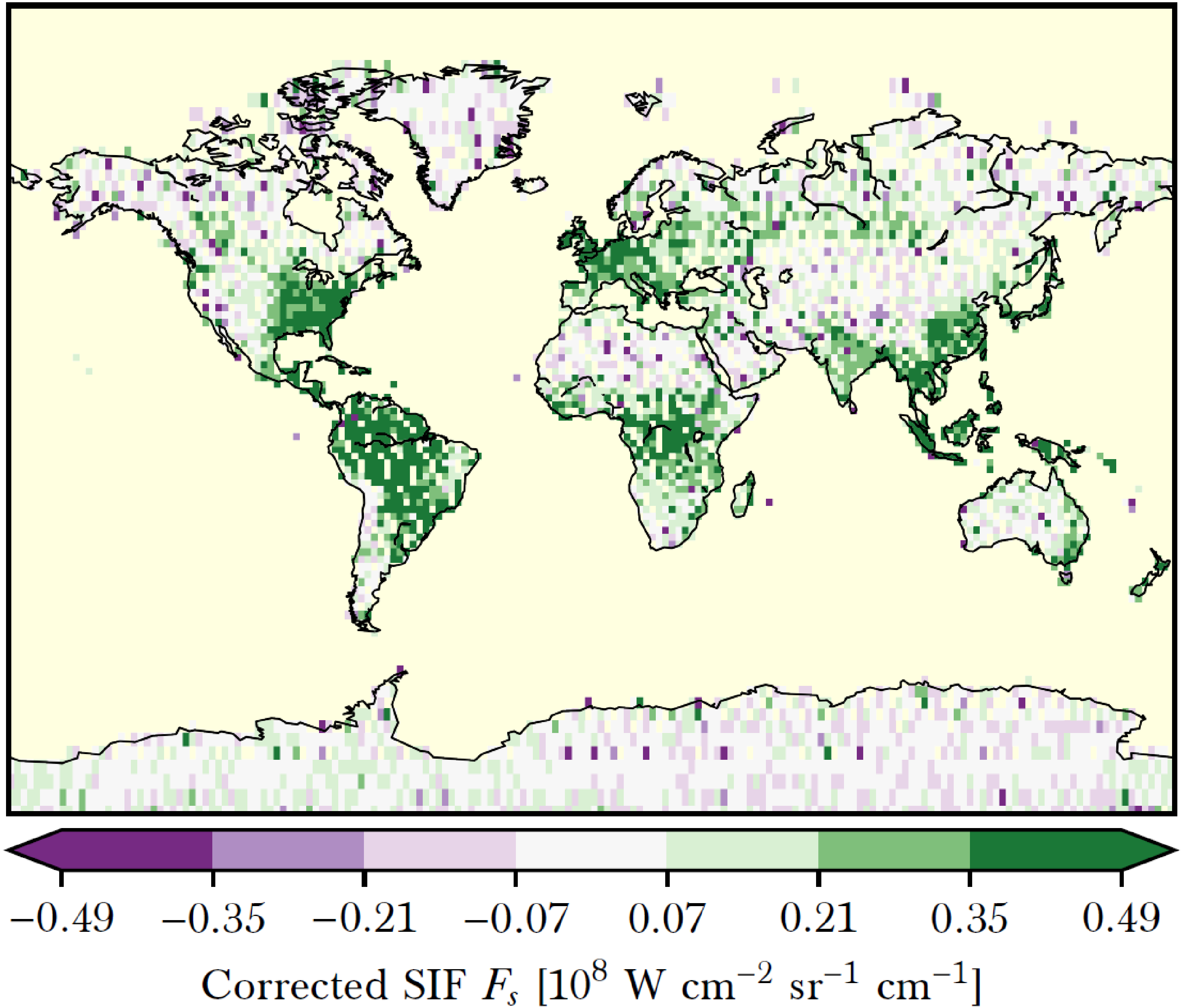
MacBean, N., Maignan, F., Bacour, C., Lewis, P., Peylin, P., Guanter, L., Köhler, P., Gómez-Dans, J. and Disney, M., 2018. Strong constraint on modelled global carbon uptake using solar-induced chlorophyll fluorescence data. *Scientific reports*, *8*(1), p.1973.

NCEO GOSAT SIF

- Part of the NCEO Leicester Full Physics Retrieval algorithm for XCO_2
- Retrieves SIF at 772nm and 755nm at S and P polarisations.



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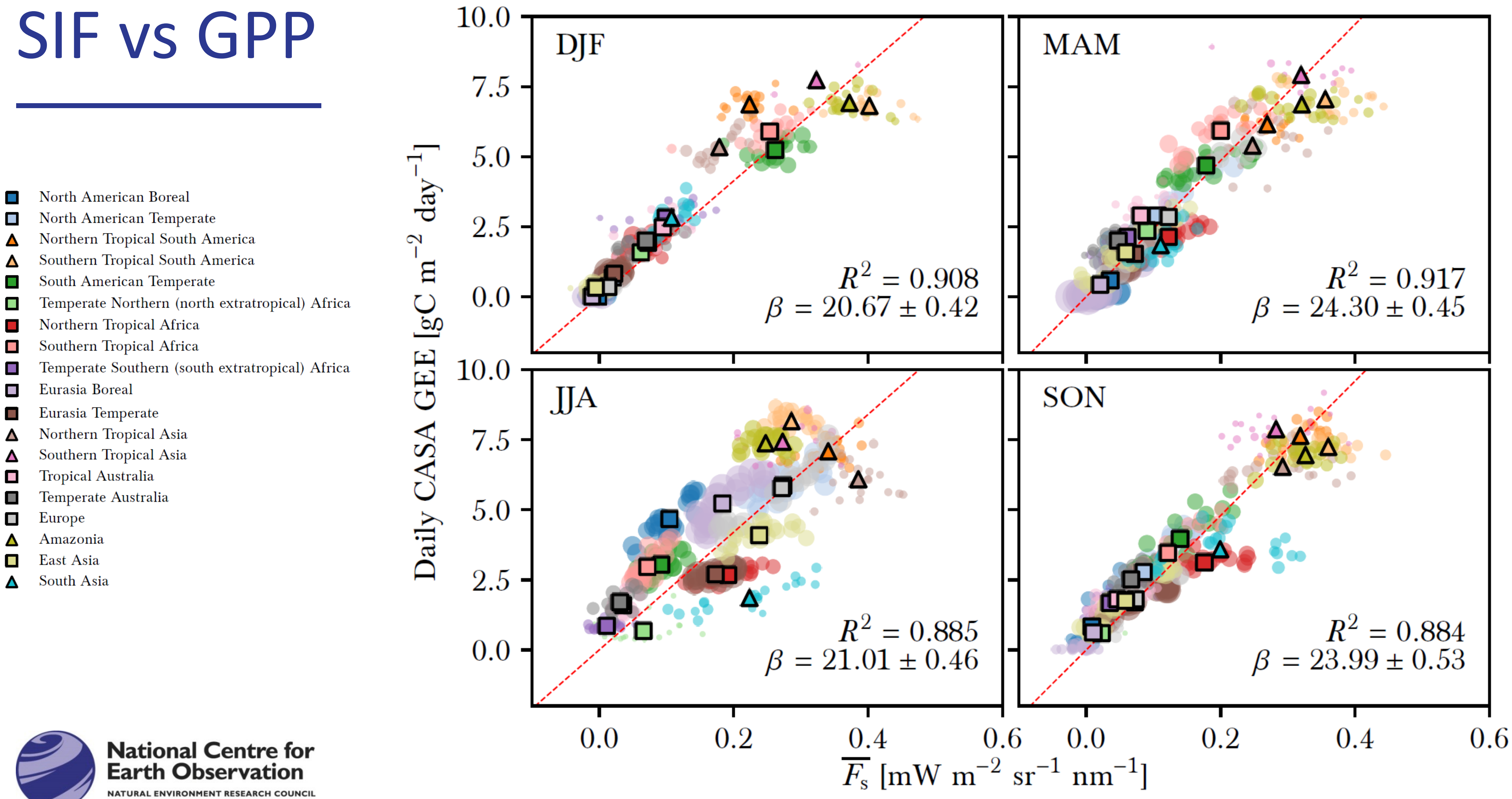
SIF vs GPP



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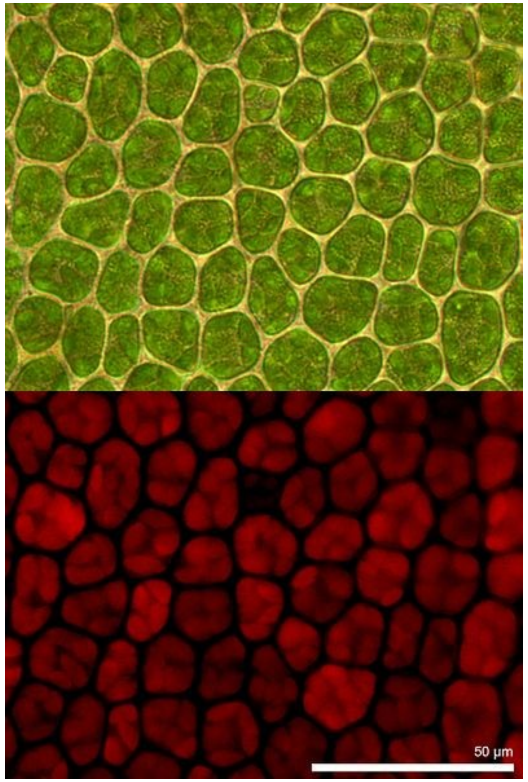
Leaf scale SIF model

- Following van der Tol *et al.* (2014), quantum SIF yield:

$$\varphi_{Ft,n} = \left[1 - \frac{J_n}{APAR_n}\right]\varphi_{F'm,n}$$

- Where J_n is the rate of electron transport (calculated by JULES) and $\varphi_{F'm,n}$ is the maximum SIF yield.
- Assuming isotropic emission SIF in layer n is given by:

$$S_n = 0.5 \times \varphi_{Ft,n} \times APAR_n$$



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Two-stream canopy scale SIF model

- Layer optical properties from Meador and Weaver (1980):

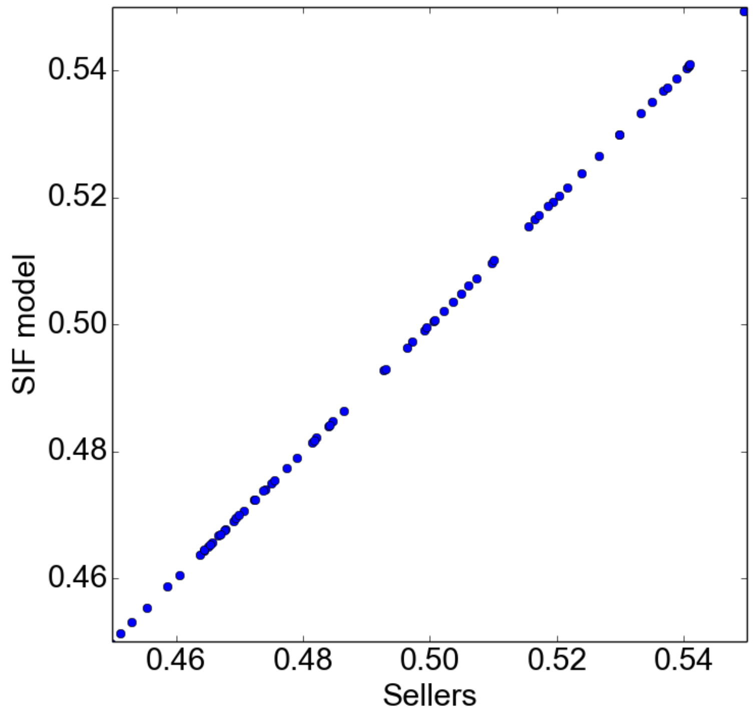
$$R = \frac{\gamma_2(1 - e^{-2\delta\tau})}{\delta + \gamma_1 + (\delta - \gamma_1)e^{-2\delta\tau}}, T = \frac{2\delta e^{-\delta\tau}}{\delta + \gamma_1 + (\delta - \gamma_1)e^{-2\delta\tau}}, \delta = \sqrt{\gamma_1^2 - \gamma_2^2}$$

- Canopy SIF solution from adding method:

$$\mathrm{SIF} = \sum_{n=1}^{N} S_n \, T_{n-½}(1 + R_{N-n+½}) \left(1 + \frac{R_{n-½} R_{N-n+½}}{1 - R_{n-½} R_{N-n+½}}\right)$$

Consistency with JULES canopy RT

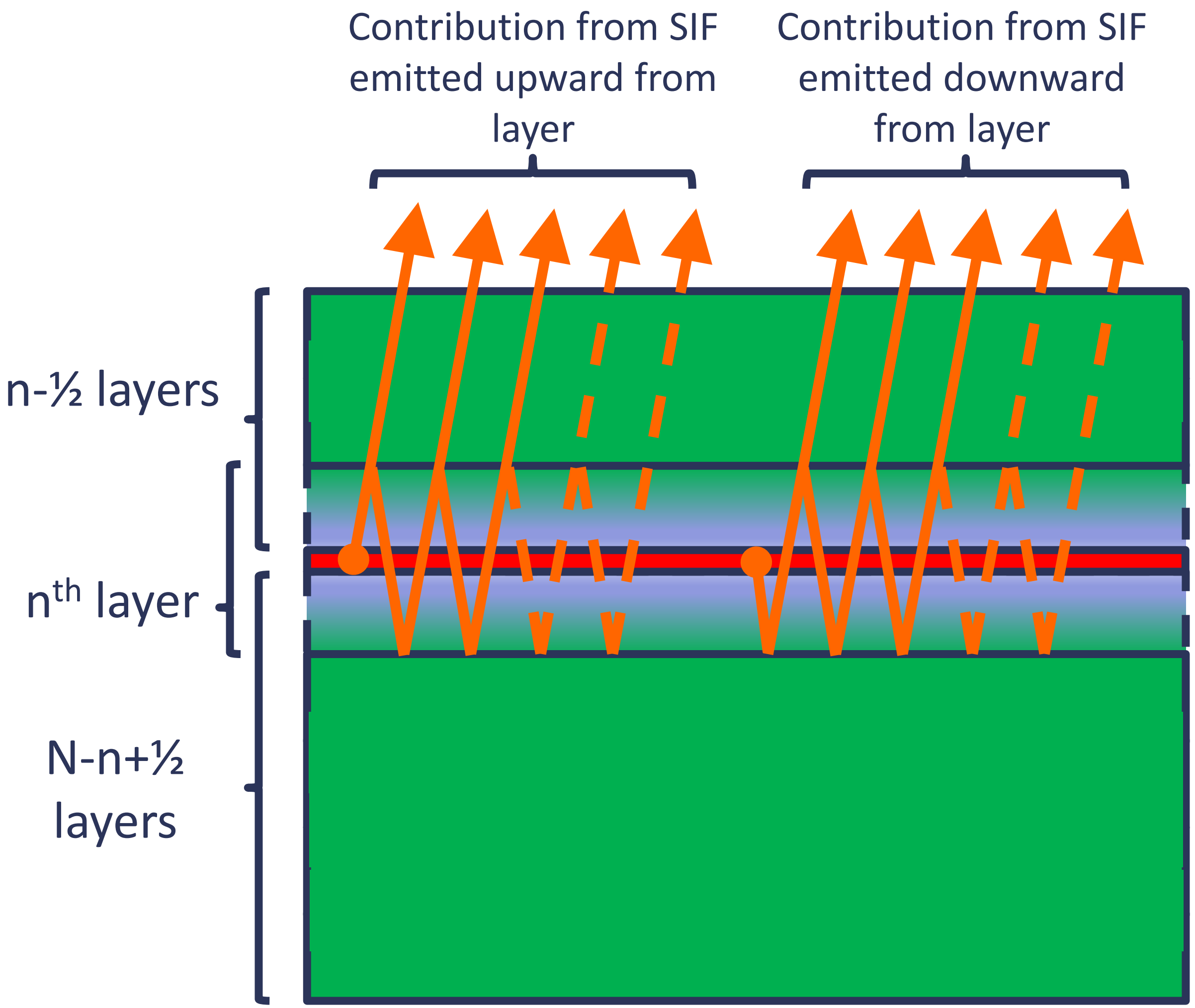
- JULES uses the Sellers (1985) model to compute canopy absorption and albedo
  - SIF model can also compute these properties
- Careful selection of γ_n yields a solution that is numerically equivalent to Sellers
  - RMSD in the order 10^{-17}
- Resulting RT model is physically consistent with scattering processes in the JULES model



Within canopy fluxes computed from the SIF model and JULES RT

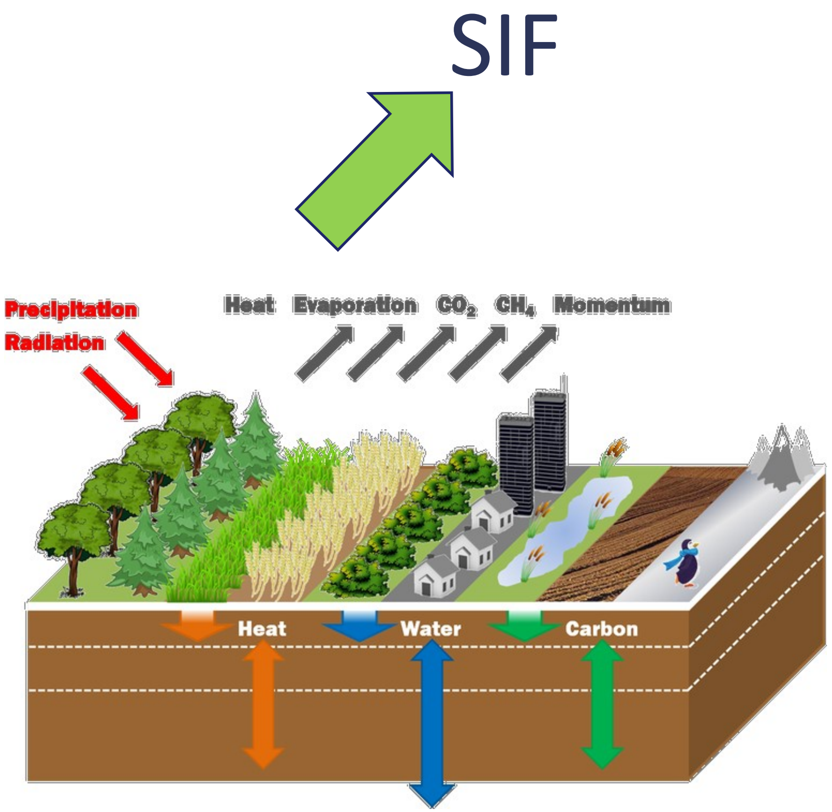
SIF canopy model

- Treats all orders of scattering
- Emission assumed to come from the centre of each layer
- Predicts the outgoing hemispheric flux



Current implementation in JULES

- Modify JULES to output per-canopy layer variables:
  - GPP, APAR
  - Generates *large* output files
- Run SIF model “off-line” from main JULES run
  - Efficient way of experimenting with the SIF model
- Needs one additional variable from JULES…



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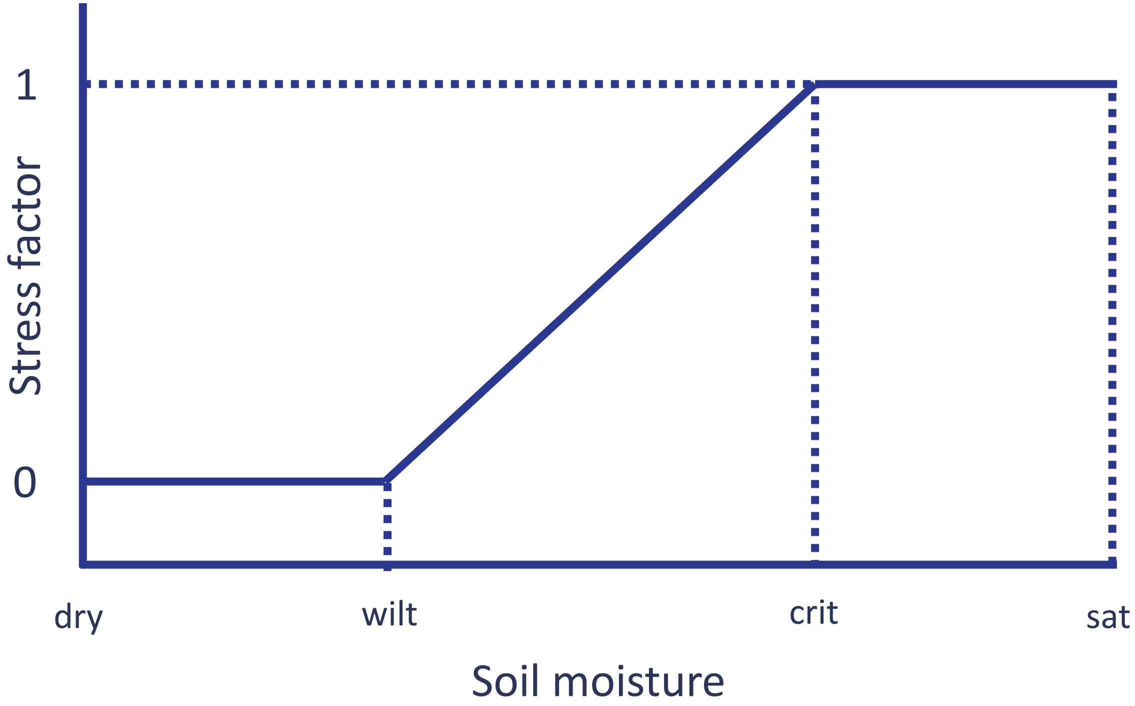
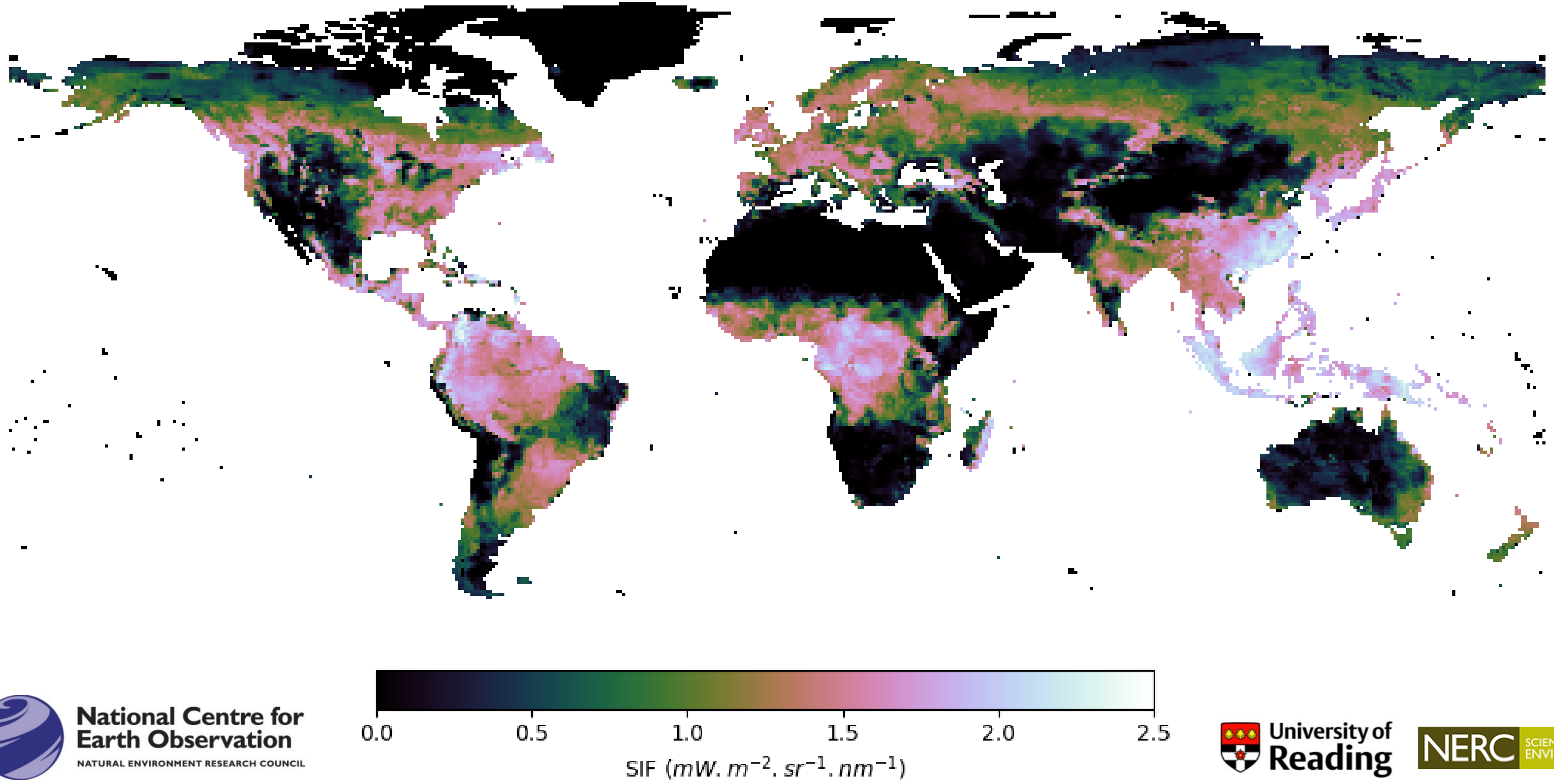
JULES water stress model

- JULES represents impact of stress on GPP using a piecewise linear model
  - Similar to other global land surface models!
- Modifies GPP *after* the calculations of the Farquhar model
- Consequently approach taken in SIF model is to scale SIF by the same stress factor



July 2016



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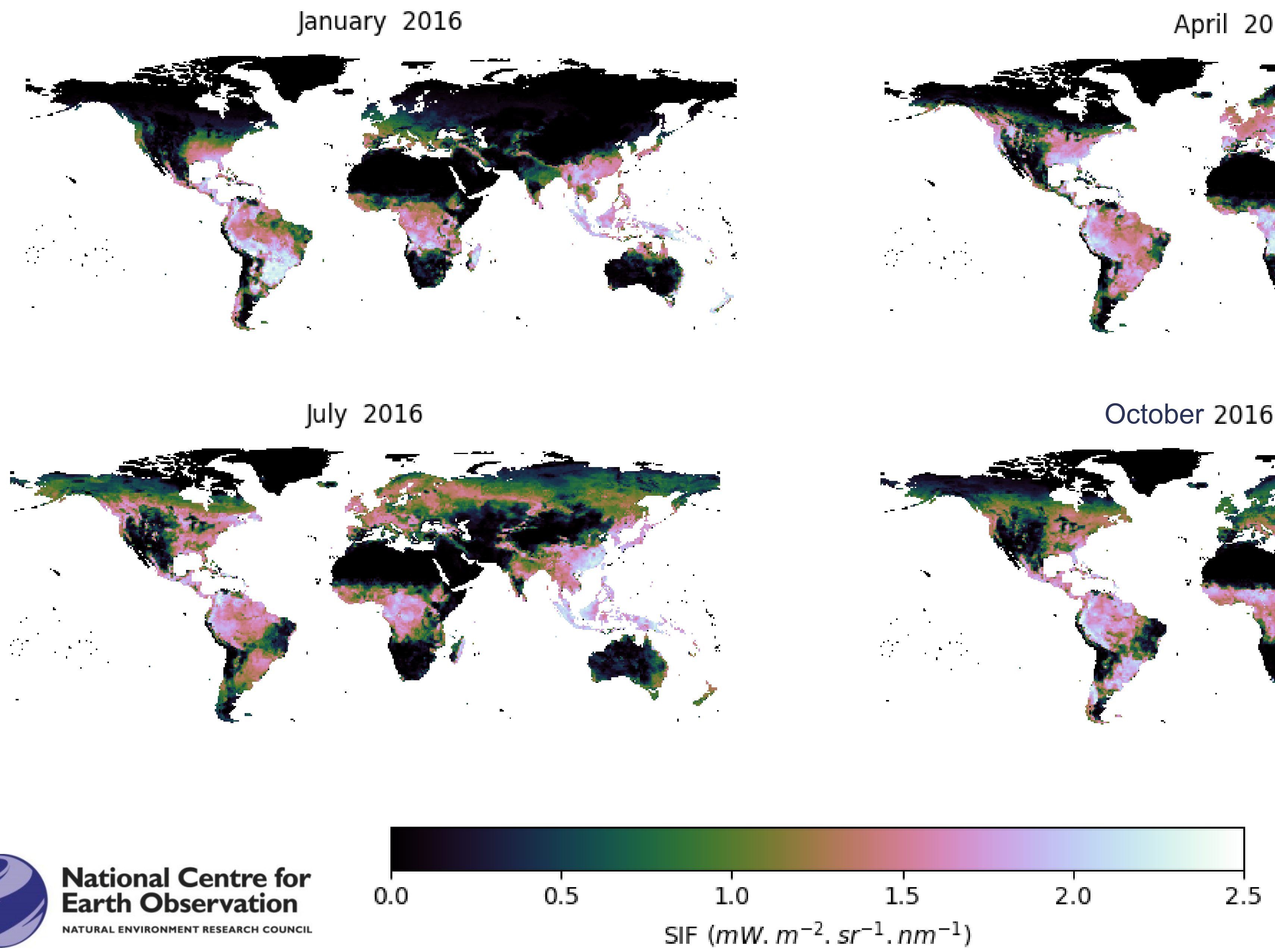
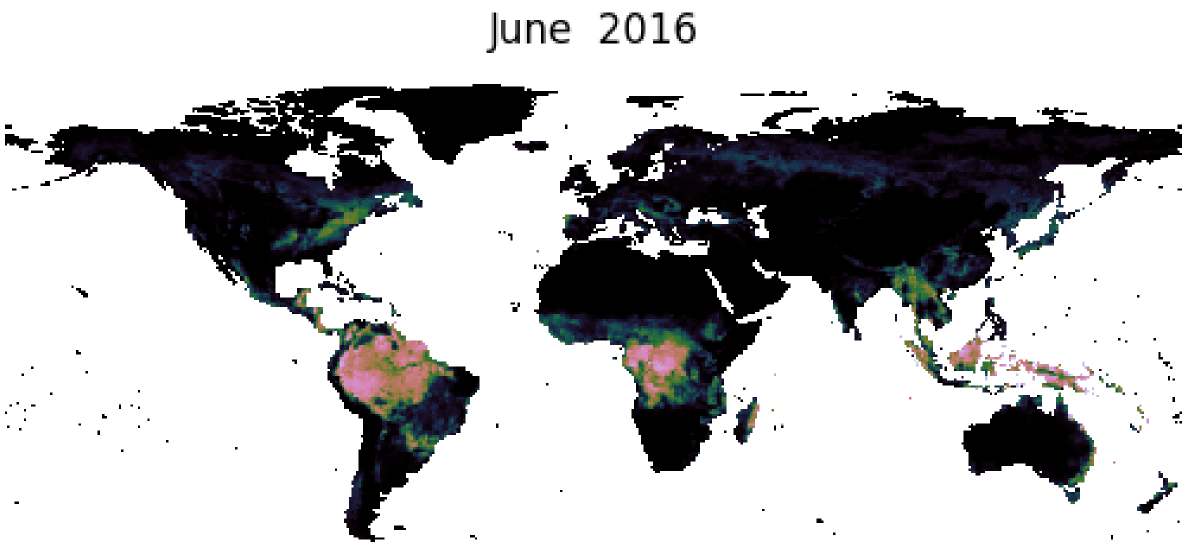
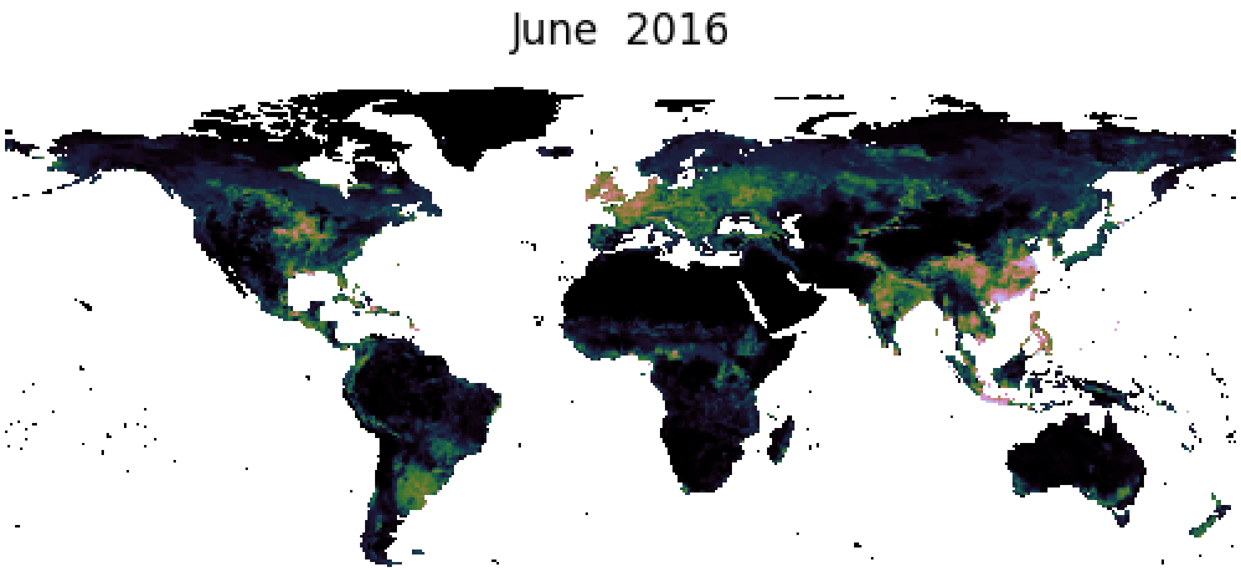
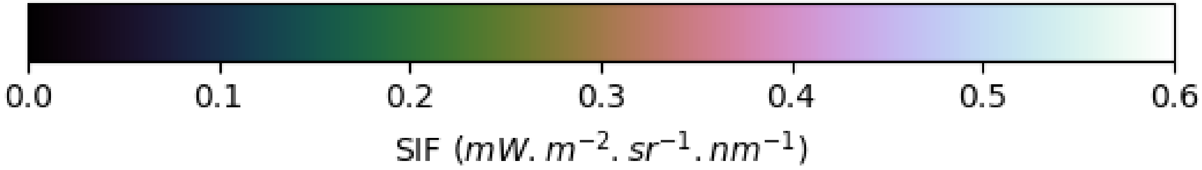

January 2016
April 2016
July 2016
October 2016
0.0
0.5
1.0
1.5
2.0
2.5
SIF $(mW.m^{-2}.sr^{-1}.nm^{-1})$

Broadleaf trees



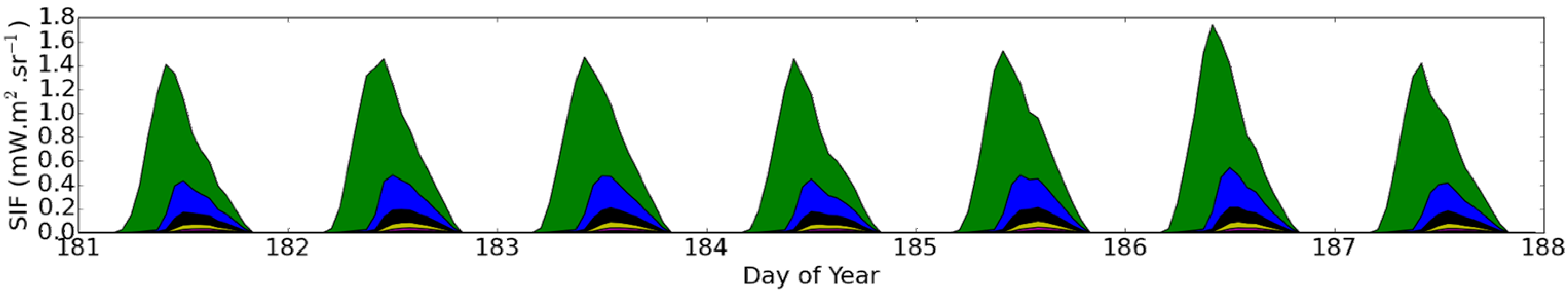
C3 grasses





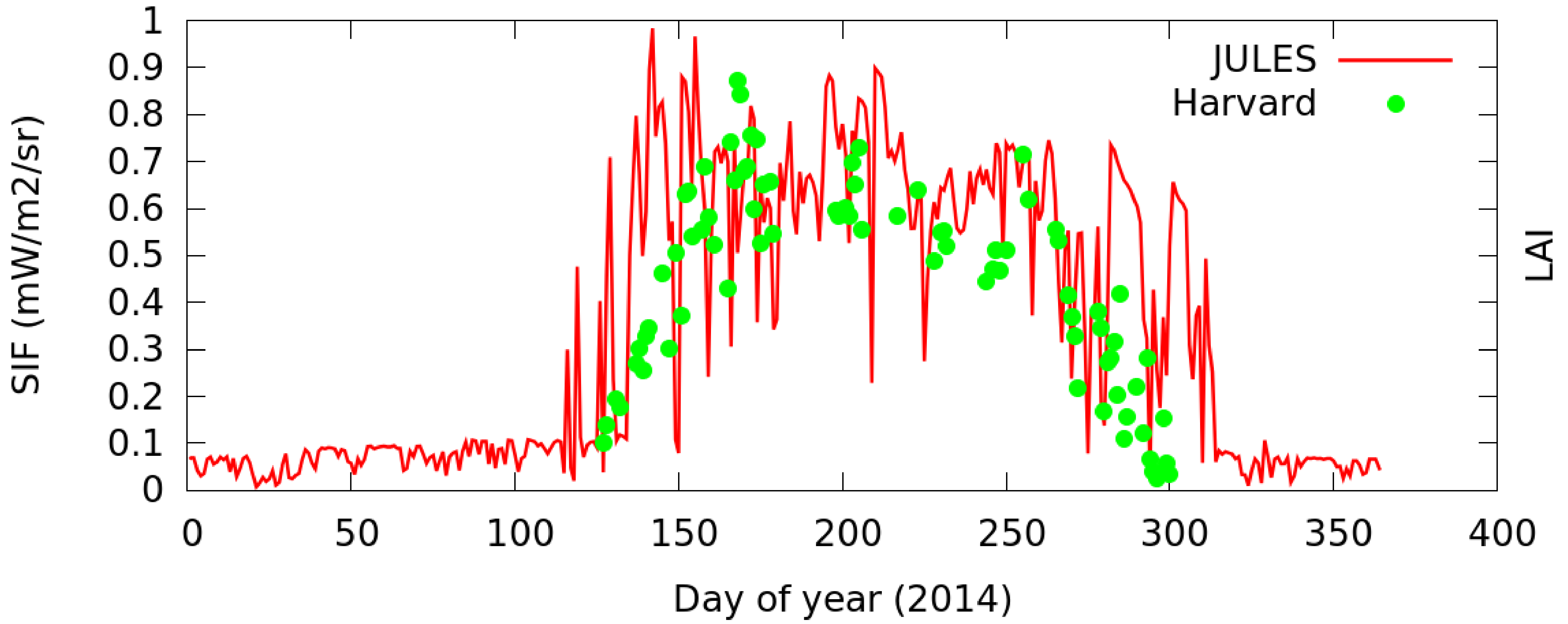
Canopy layer contributions to SIF

- Strong diurnal cycle aligned with APAR
- 90% of canopy exiting SIF from top 2 layers



Harvard forest SIF observations

Tang J. 2017. Continuous Measurement of Canopy Fluorescence at Harvard Forest since 2013. Harvard Forest Data Archive: HF283.



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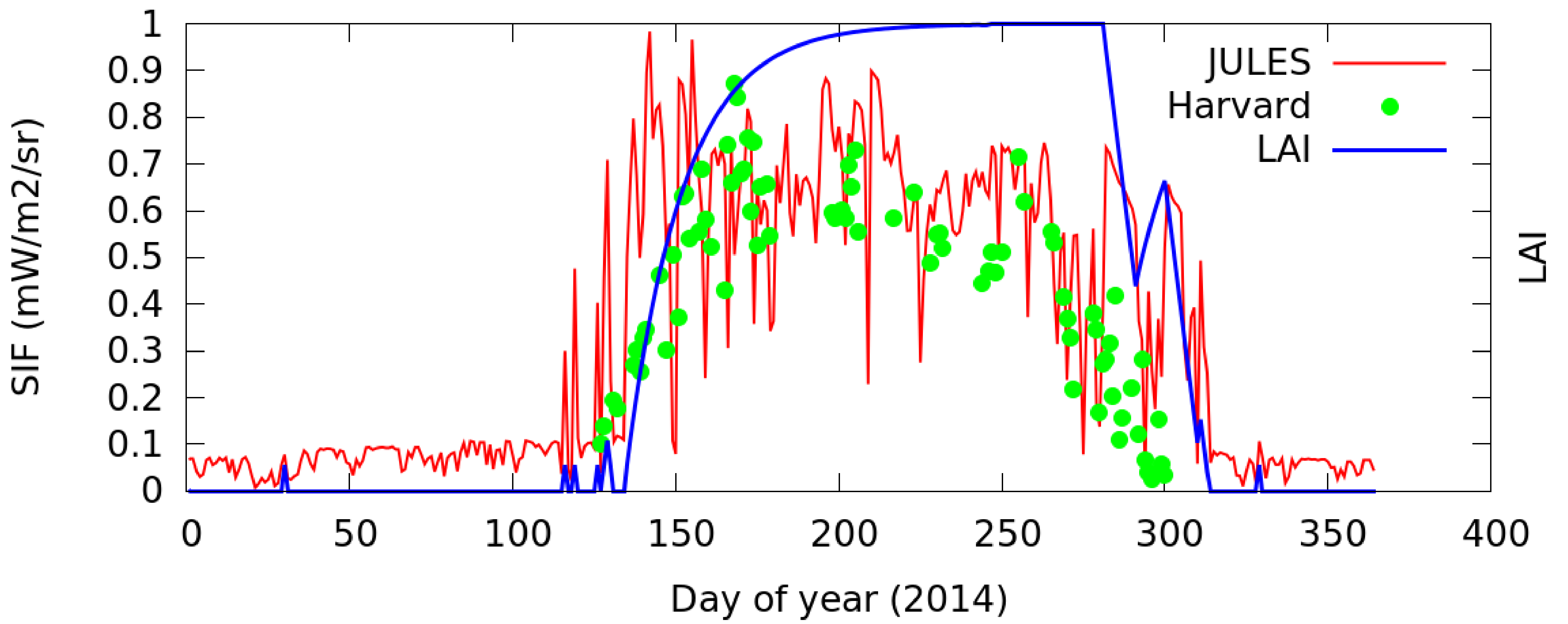

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Field campaigns

- Measuring SIF in greenhouses:
  - 3× temperature treatments
  - 2× CO_2 treatments
- Semi-permanent SIF spectrometer going up at Alice Holt later this year
- Collaborating with BiFor team

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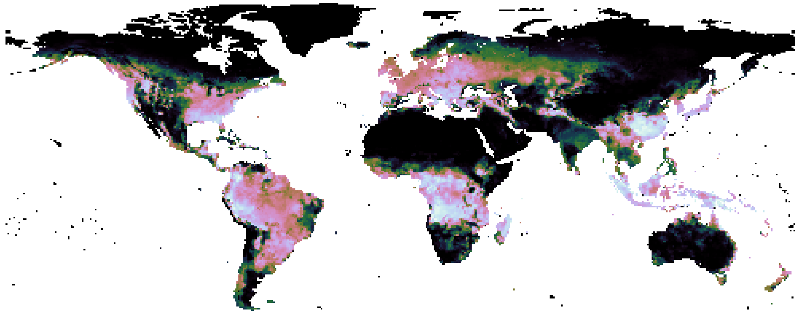
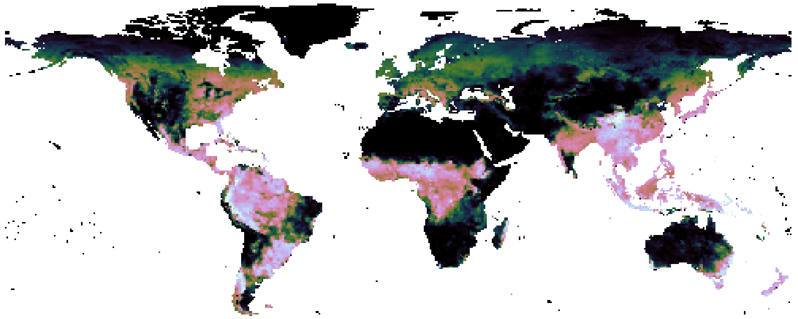
Conclusions

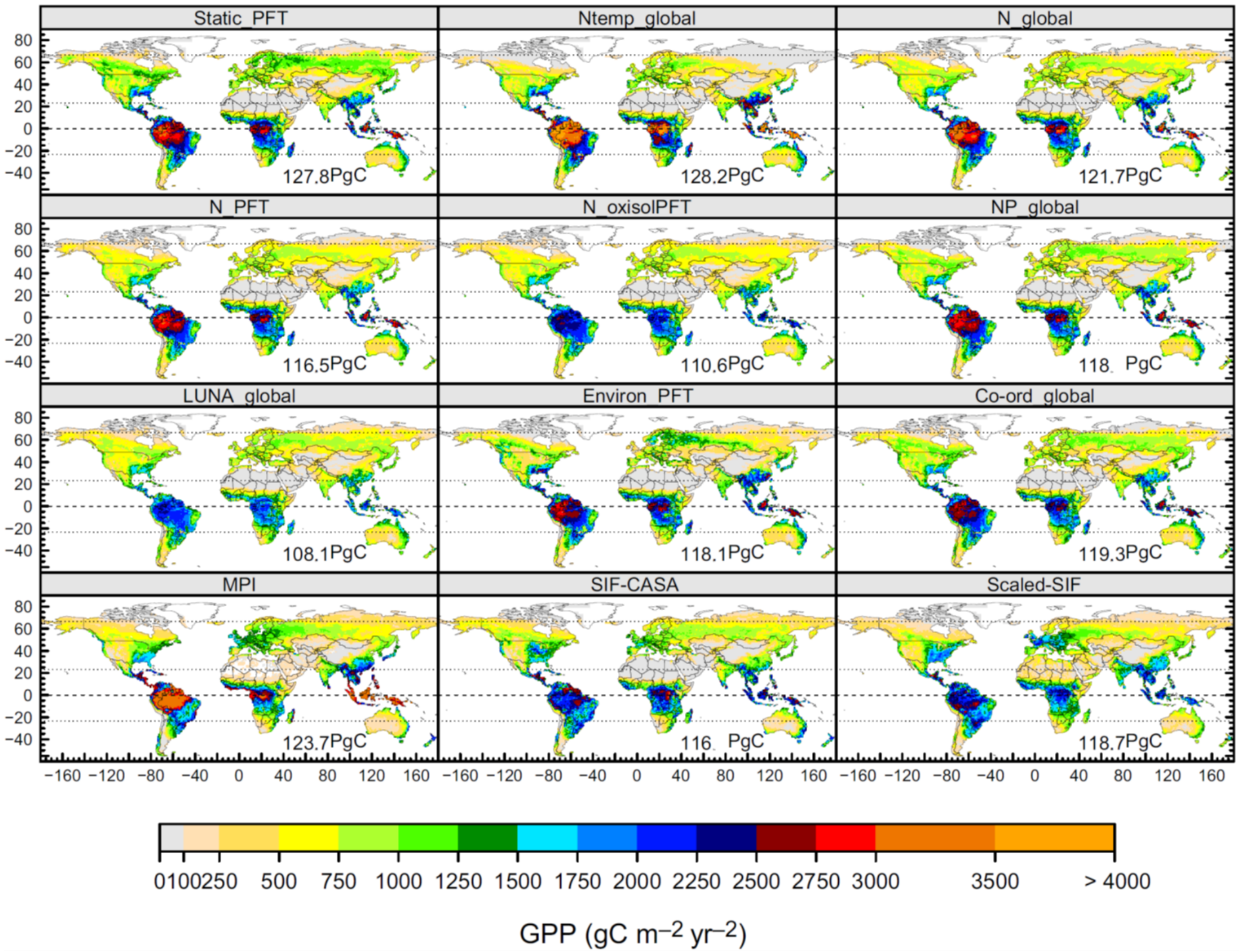
- Fully mechanistic SIF model developed for UK land model, JULES
- Currently in the process of testing against EO and in-situ observations
- Next steps:
  - NPQ model
  - Stress model
  - Directional signal





Testing model hypotheses about GPP

Walker, A.P., Quaife, T., Bodegom, P.M., De Kauwe, M.G., Keenan, T.F., Joiner, J., Lomas, M.R., MacBean, N., Xu, C., Yang, X. and Woodward, F.I., 2017. The impact of alternative trait-scaling hypotheses for the maximum photosynthetic carboxylation rate (Vcmax) on global gross primary production. *New Phytologist*, *215*(4), pp.1370-1386.



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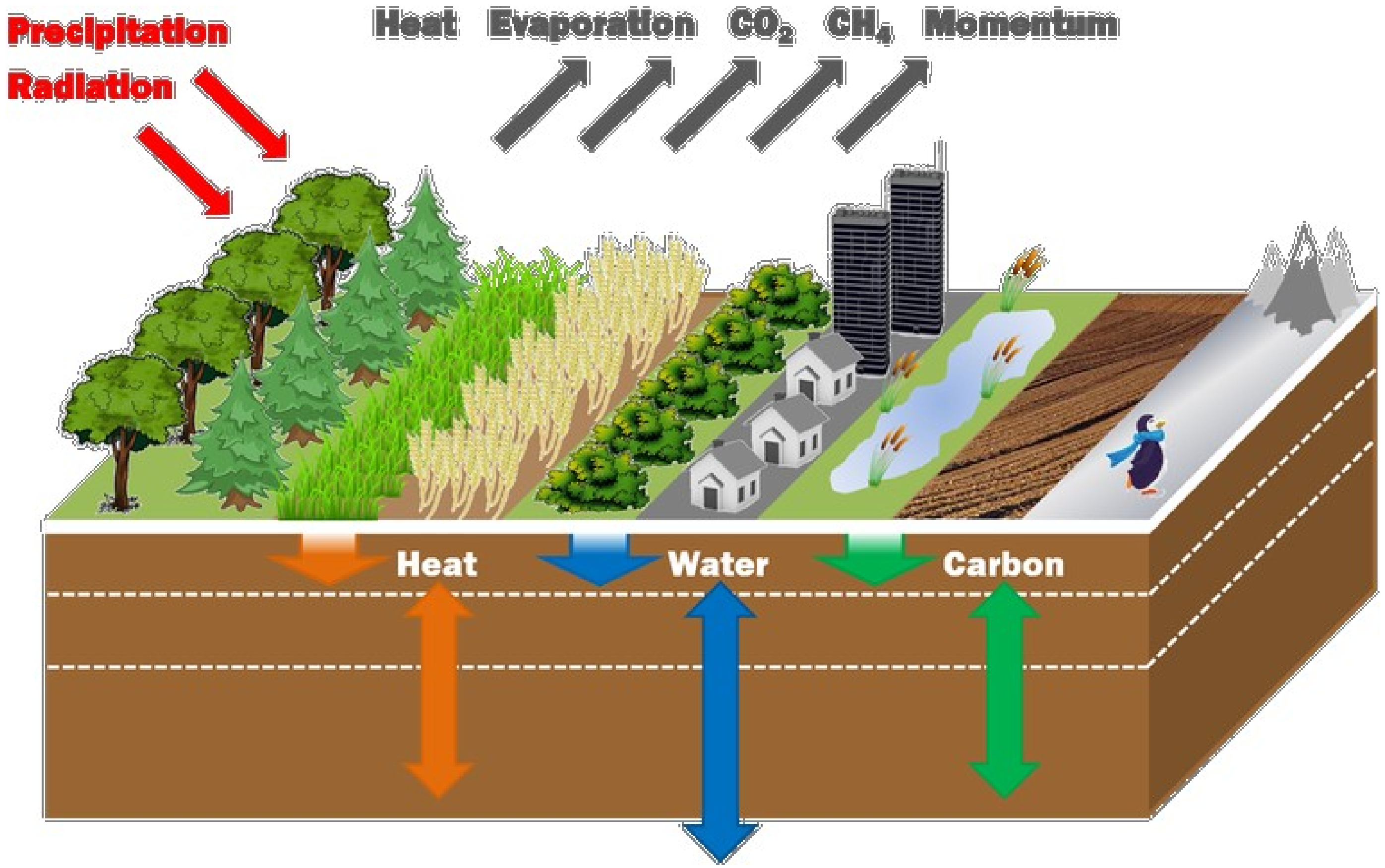
JULES - UKESM Land Surface Model

- Can be run “online” in a climate model or forced by observed meteorology
- Spatial and temporal resolution defined by forcing
- In this presentation:
  - WFDEI meteorology
  - 3hr time step
  - 0.5° × 0.5° grid
- Farquhar equations for GPP



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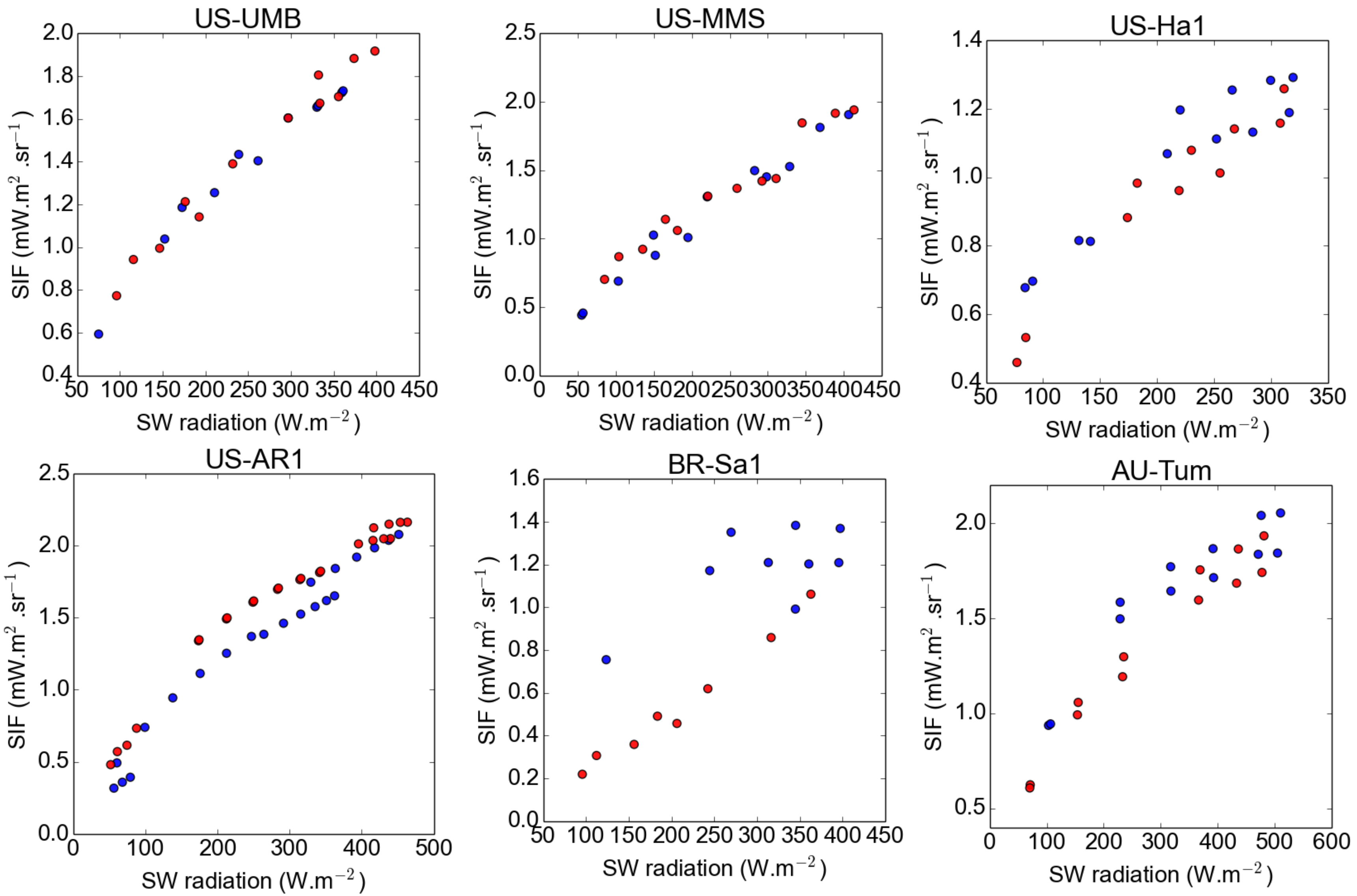
Predicted diurnal cycle

● = Morning

● = Afternoon



SIF-G