Co-ordinated by ECMWF

CoCO2 Prototype system for a Copernicus CO_2 service

TOWARDS DYNAMICALLY UPDATED VEGETATION IN NWP

IESWG-5

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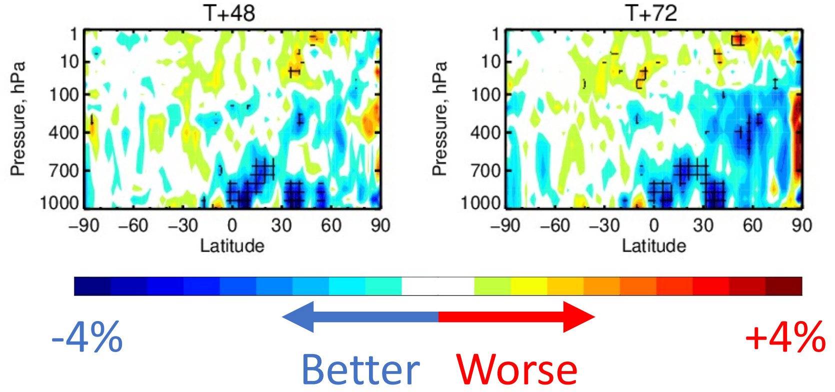
Outline

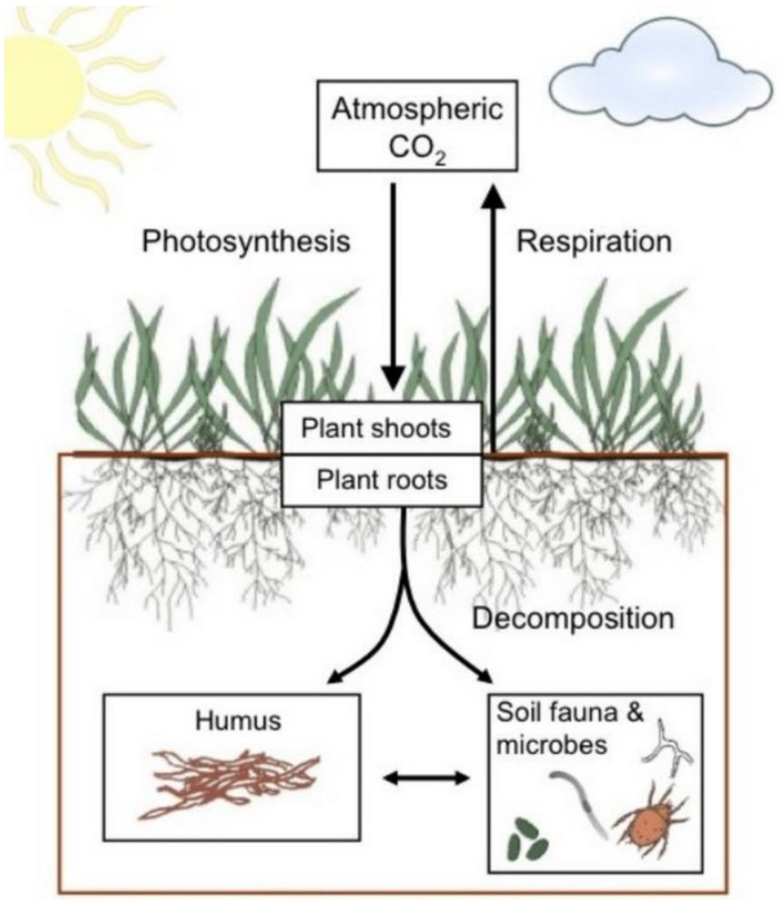
- Motivation
- Methodology
  - Observations
  - Assimilation configuration
- Results
  - NWP
  - Carbon cycle
- Conclusions and future work

Motivation

- There is currently no prognostic vegetation model in the IFS
- Vegetation parameters such as leaf area index (LAI) and vegetation cover are currently supplied via fixed climatologies
  - No inter-annual changes are accounted for
- Upcoming changes to the vegetation parameter climatologies in the next ECMWF cycle 49r1 contribute to significant NWP impacts
- Aim to have a more dynamic representation of the carbon cycle
  - Account for missing processes e.g. irrigation
  - Feedbacks from extreme events e.g. fires, droughts
- Potential to improve the water cycle and energy balance



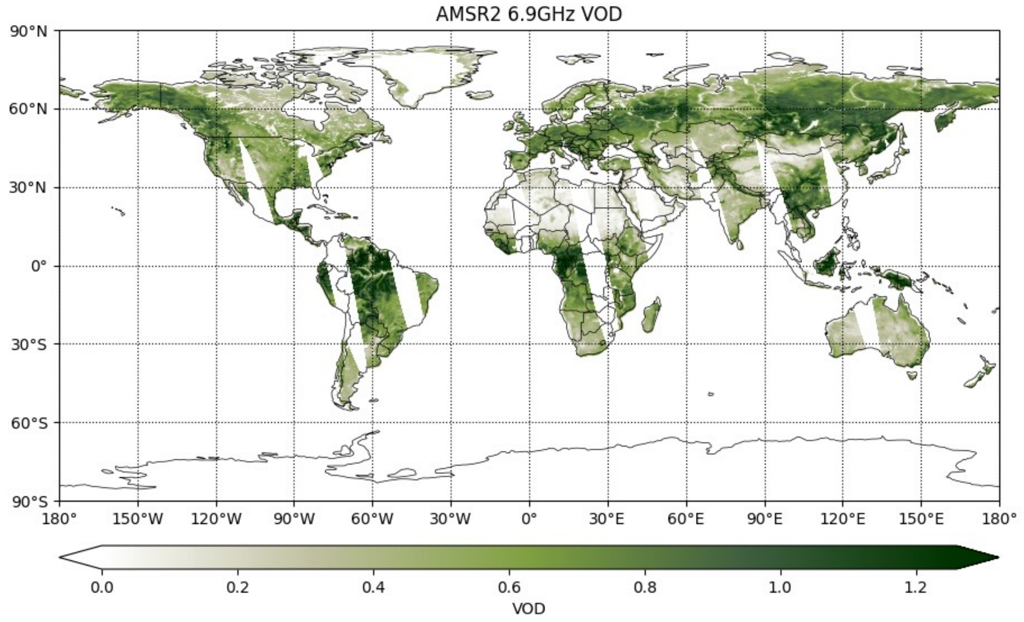
Souhail Boussetta

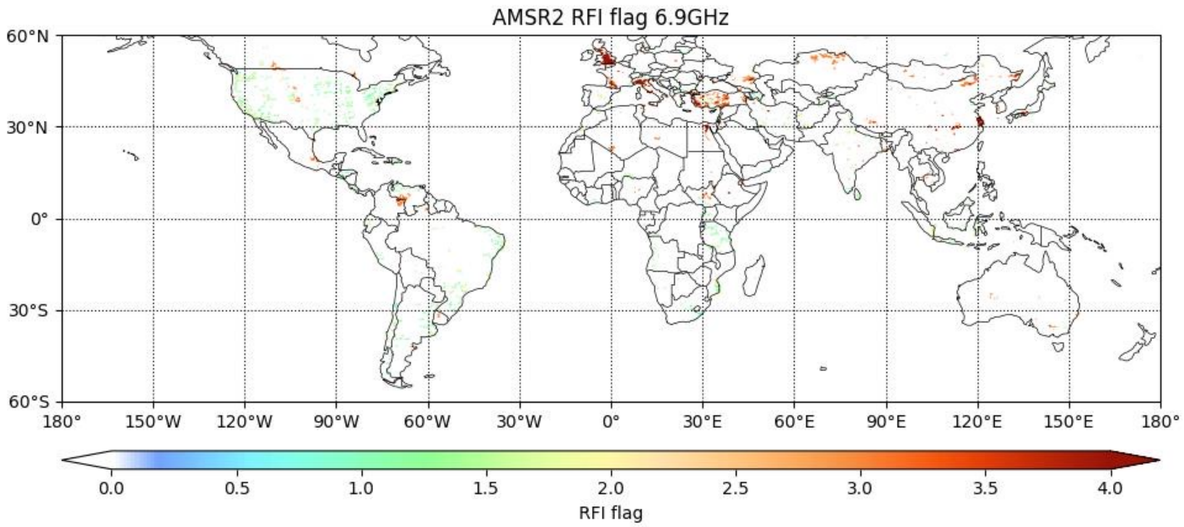


Ontl, T. A. & Schulte, L. A. (2012)

Observations

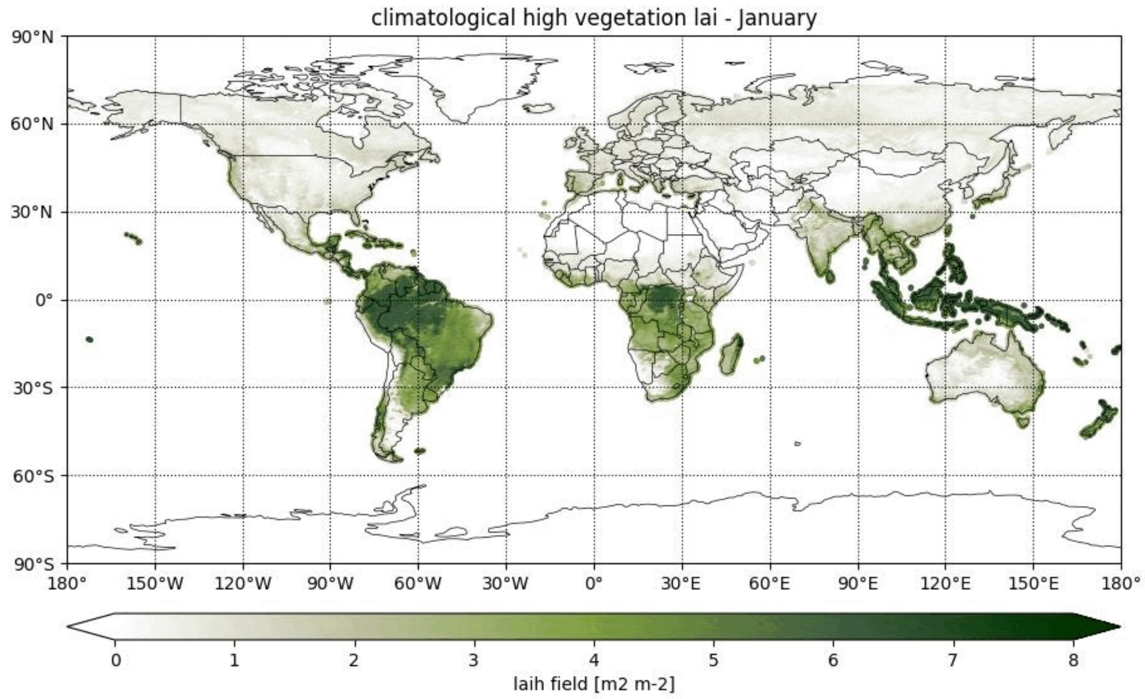
- Traditional optical LAI observations take many days to obtain global coverage due to cloud contamination
- Vegetation optical depth (VOD) observations have daily global coverage and are insensitive to clouds
- VOD is a measure of the attenuation of MW radiances due to vegetation water content
- We use VOD observations from SMOS (L-band) and AMSR2 (C-, X-band)
- Basic quality control applied (e.g. RFI, unphysical values, snow and frozen ground)





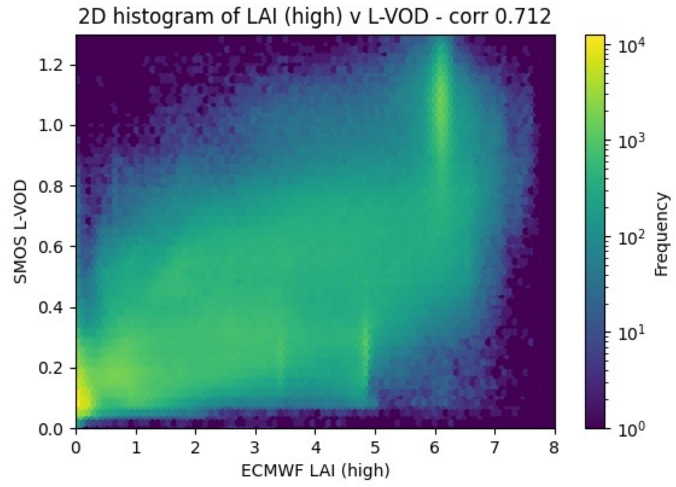
Climatological LAI

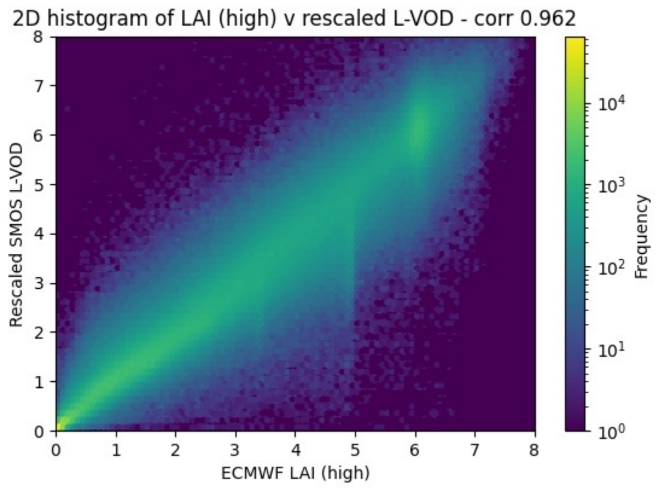
- Time-varying LAI is available from monthly CONFESS data (based on CGLS dataset):
  - Inter-annual changes are accounted for
  - High quality data from 2000-2019
  - Uses SPOT, PROBA-V optical sensors
  - **Used to rescale the VOD observations to a model-like LAI**
- Latest LAI climatology used in the IFS is a weighted mean of the monthly CONFESS data
  - Monthly climatology so seasonal changes are included
  - LAI for high and low vegetation types considered separately (including new disaggregation)
  - No inter-annual changes are considered
  - **Used as the background in our assimilation scheme**



CDF-matching to rescale VOD

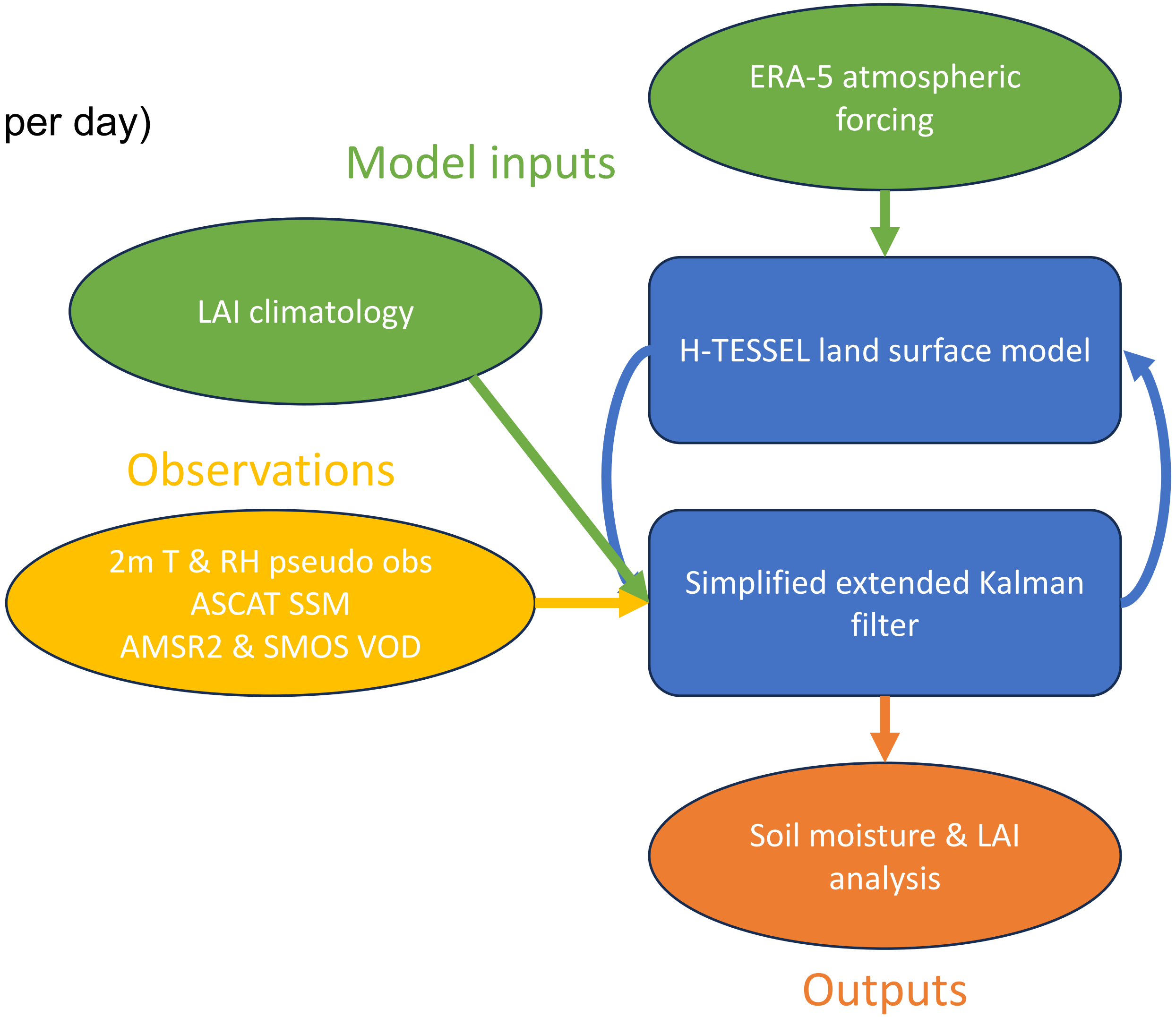
- LAI and VOD are correlated but have different units and scales
- No observation operator available (see future/ongoing work…)
- CDF-matching used to convert ASCAT level 2 surface soil moisture to model equivalent volumetric soil moisture
- We use similar CDF-matching approach to rescale VOD to LAI
  - VOD observations from SMOS (L-band) and AMSR2 (C- and X-band)
  - CONFESS time-varying LAI dataset (high and low veg types separate)
  - 2016-2017 data used for rescaling (validated on 2018-2019)
  - CDF-matching parameters calculated for all combinations of VOD band and LAI type





Offline land data assimilation system

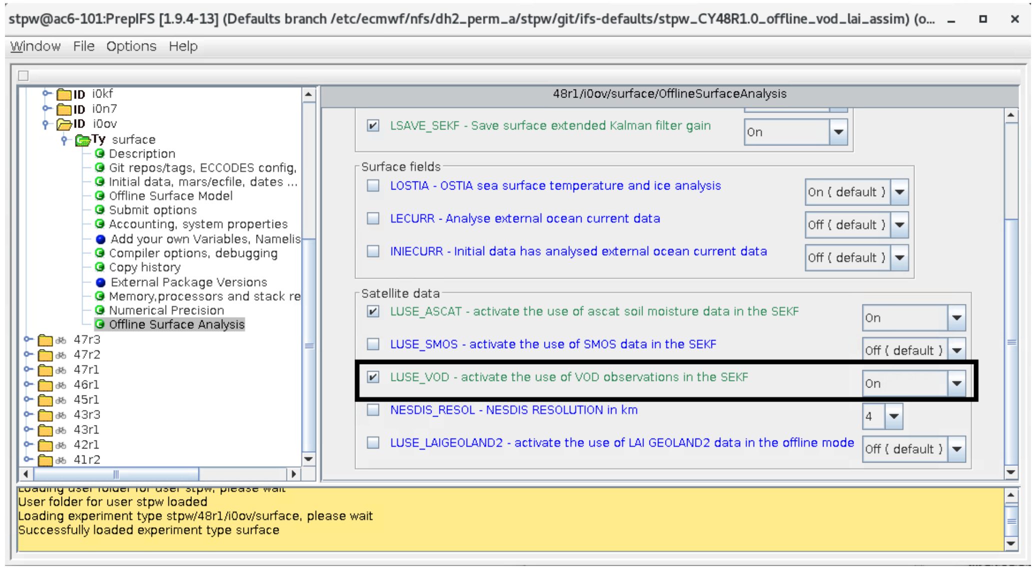
- Benefits
  - Simpler system than weakly coupled LDAS
  - Runs much faster (~100s of experiment days per day)



- Drawbacks
  - Land and atmosphere are uncoupled

Assimilating VOD to analyse LAI

- Changes to offline LDAS to:
  - Ingest VOD observations (L-, C- and X-band separately)
  - Perform rescaling, using pre-computed CDF-matching params
  - Extend control vector to include LAI (high and low)
  - Specify rescaled VOD observation (0.05) and LAI background (0.2) errors (following Mucia et al (2022))
  - Assimilate rescaled obs to produce daily LAI analysis
- Analysed LAI ingested into IFS in place of fixed climatology



Observation vector

$$\mathbf{y} = \begin{bmatrix} \mathrm{T}_{2\mathrm{m}} \\ RH_{2m} \\ ASCAT_{sm} \\ VOD_{hi} \\ VOD_{lo} \end{bmatrix}$$

Control vector

$$\mathbf{x_b} = \begin{bmatrix} SM_{l1(t)} \\ SM_{l2(t)} \\ SM_{l3(t)} \\ LAI_{hi} \\ LAI_{lo} \end{bmatrix}$$

Observation operator

$$\mathcal{H}\,[\mathbf{x_b}]) = \begin{bmatrix} \mathrm{T}_{2\mathrm{m}} \\ RH_{2m} \\ SM_{top} \\ LAI_{hi} \\ LAI_{lo} \end{bmatrix}$$

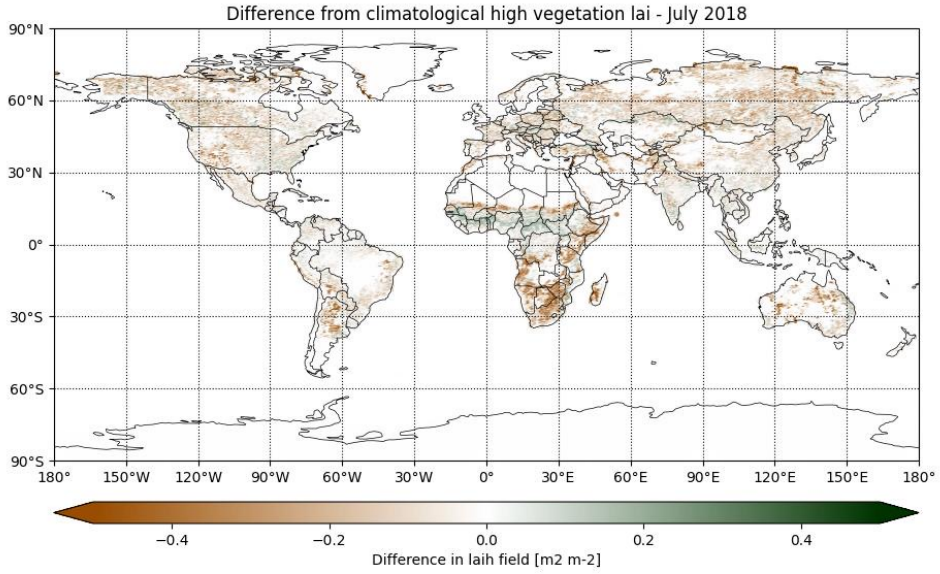
Experiments

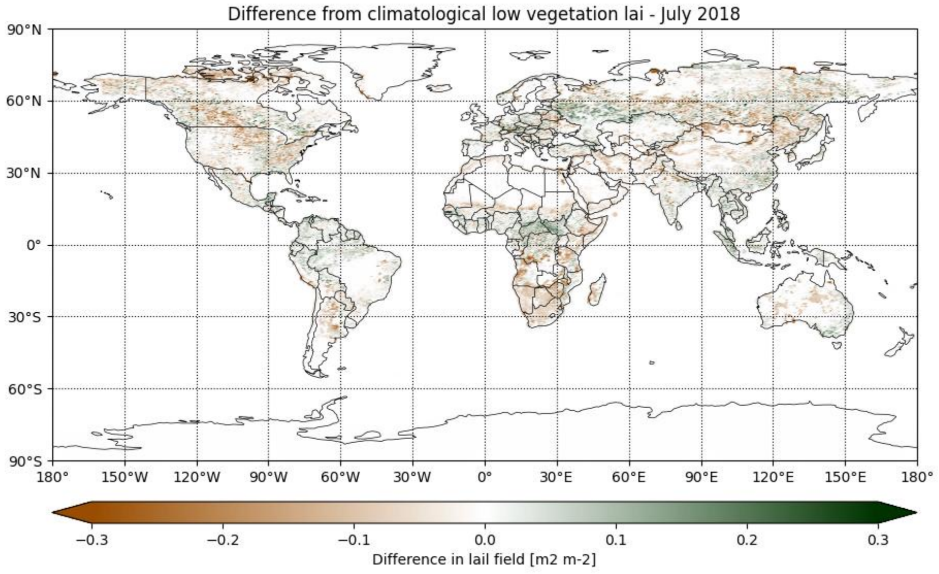
IFS experiment	Offline LDAS experiment	VOD observations assimilated	Period
IFS-CTRL	LDAS-CTRL	None	Jan 2018 – Dec 2021
IFS-L-VOD	LDAS-L-VOD	SMOS L-VOD (1.4GHz)	Jan 2018 – Nov 2021
IFS-C-VOD	LDAS-C-VOD	AMSR2 C-VOD (6.9GHz)	Jan 2018 – Dec 2021
IFS-X-VOD	LDAS-X-VOD	AMSR2 X-VOD (10.7GHz)	Jan 2018 – Dec 2021

- All experiments run at T_{CO}319 (~30km) resolution over the global domain
- Offline LDAS experiments are uncoupled
- IFS experiments are “forecast only”
  - Atmospheric analysis comes from operations
  - Only differences are land fields (including LAI) coming from offline LDAS experiments
  - Will give a measure of the atmospheric impact of the vegetation changes

Analysis increments

- Analysis increments look reasonable
  - No huge changes despite relatively high observation weights
- High LAI increments are skewed negative (particularly in extra-tropics)
  - Possibly due to maximum value threshold on analysed LAI
- Low LAI increments are more balanced

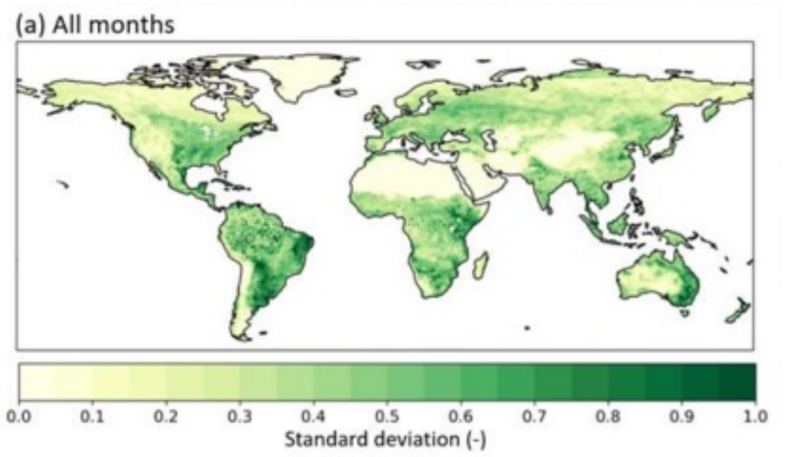




NWP results

- Small but significant improvements to surface and lower tropospheric temperature and humidity forecasts
  - Especially over forested areas e.g. Amazon
  - Impacts are collocated with largest inter-annual variations in CONFESS time-varying vegetation

Standard deviation of inter-annual LAI anomalies 1993-2019

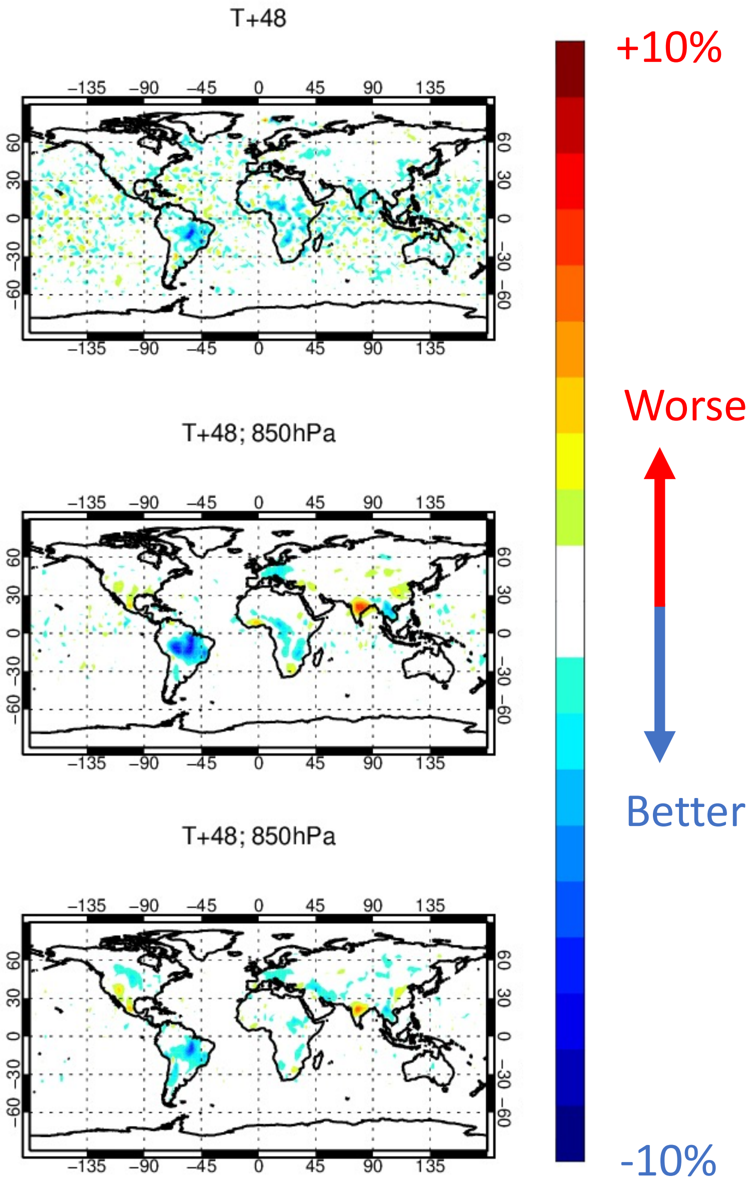


From Alessandri, 2022 [CONFESS report]

2m temperature

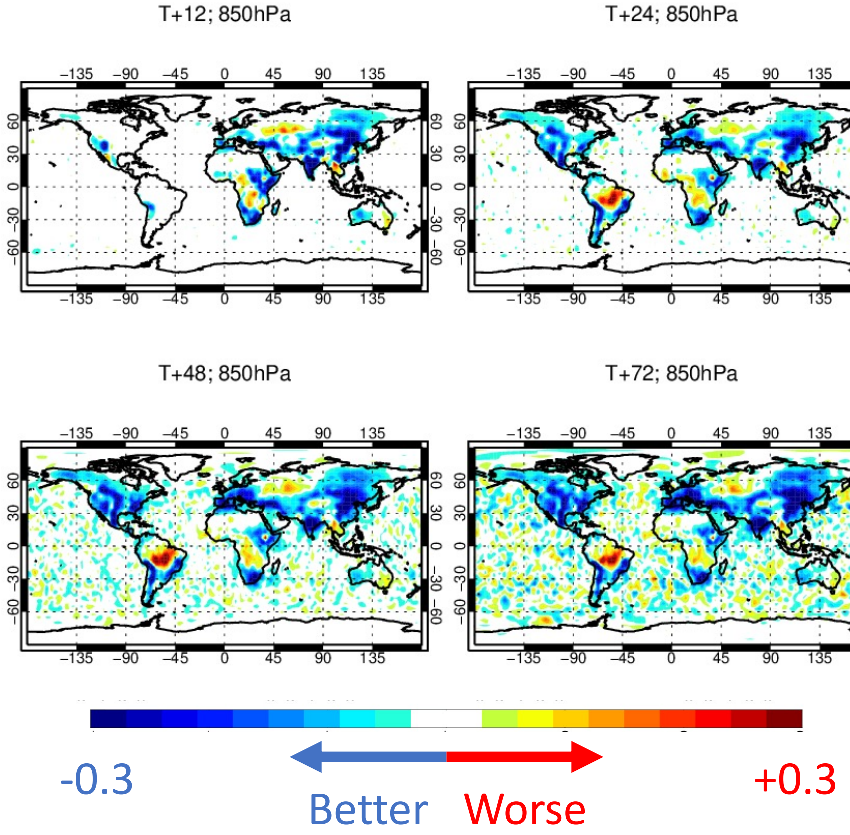
850hPa temperature

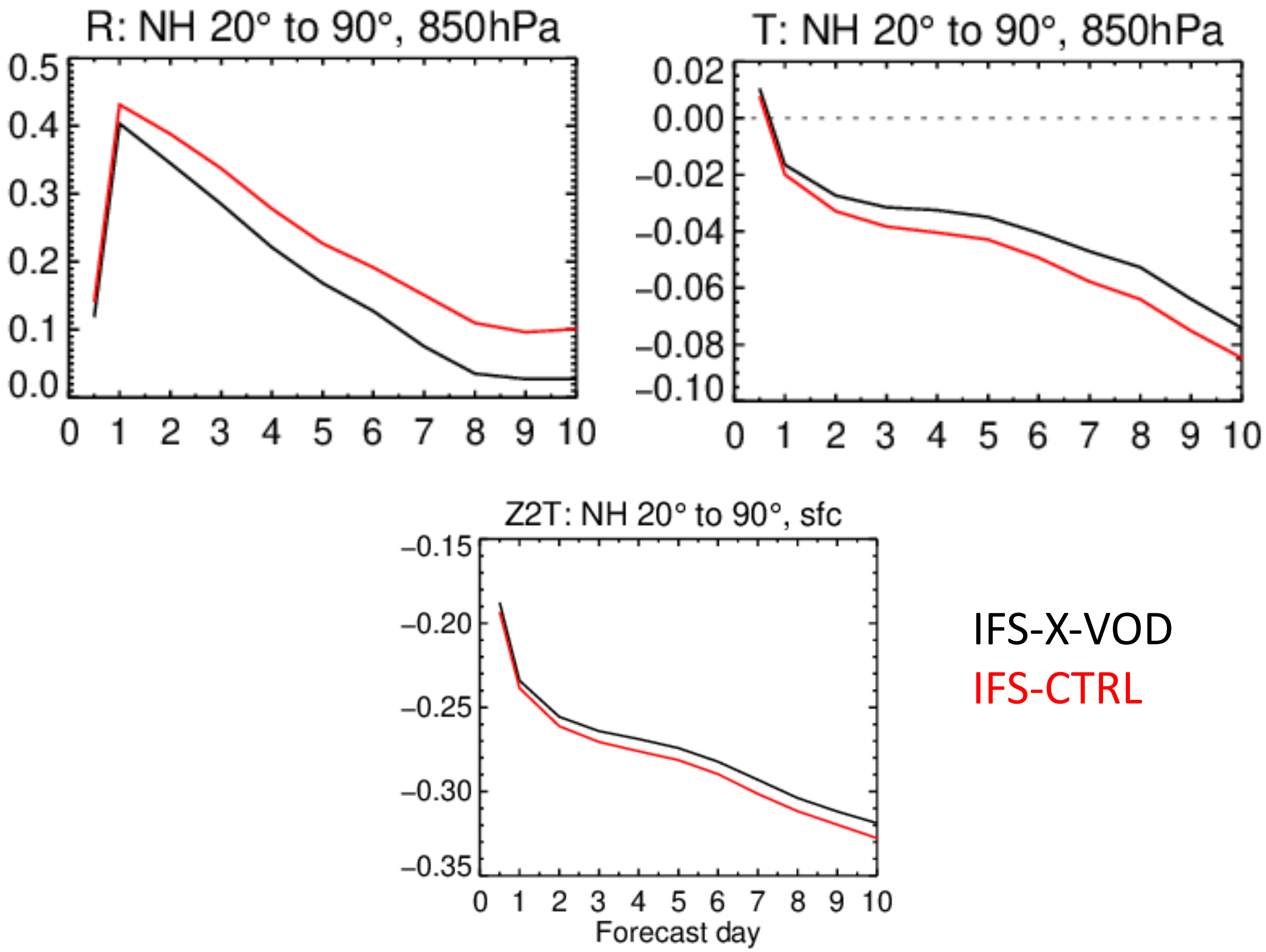
850hPa relative humidity



NWP results

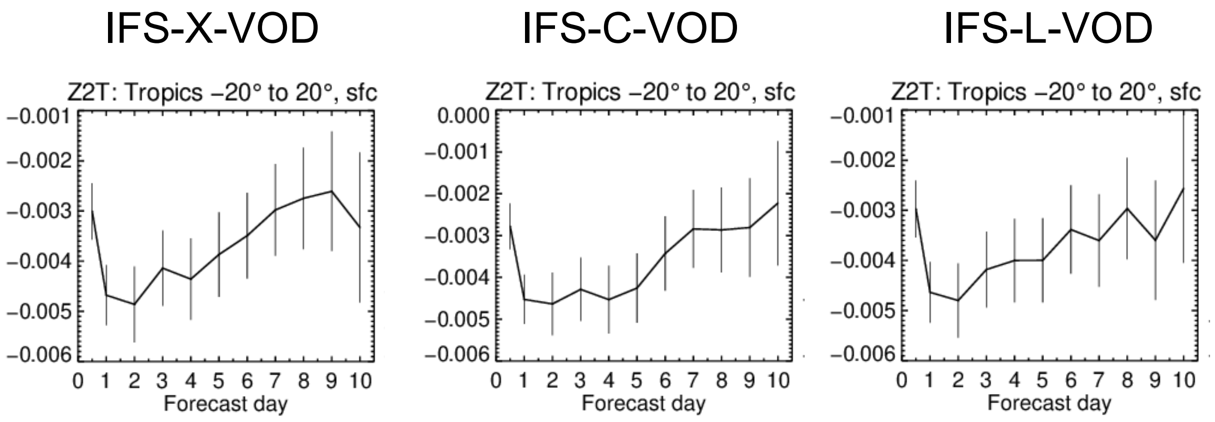
- Consistent reduction in mean errors
  - Tropospheric humidity
  - Tropospheric and surface temperature

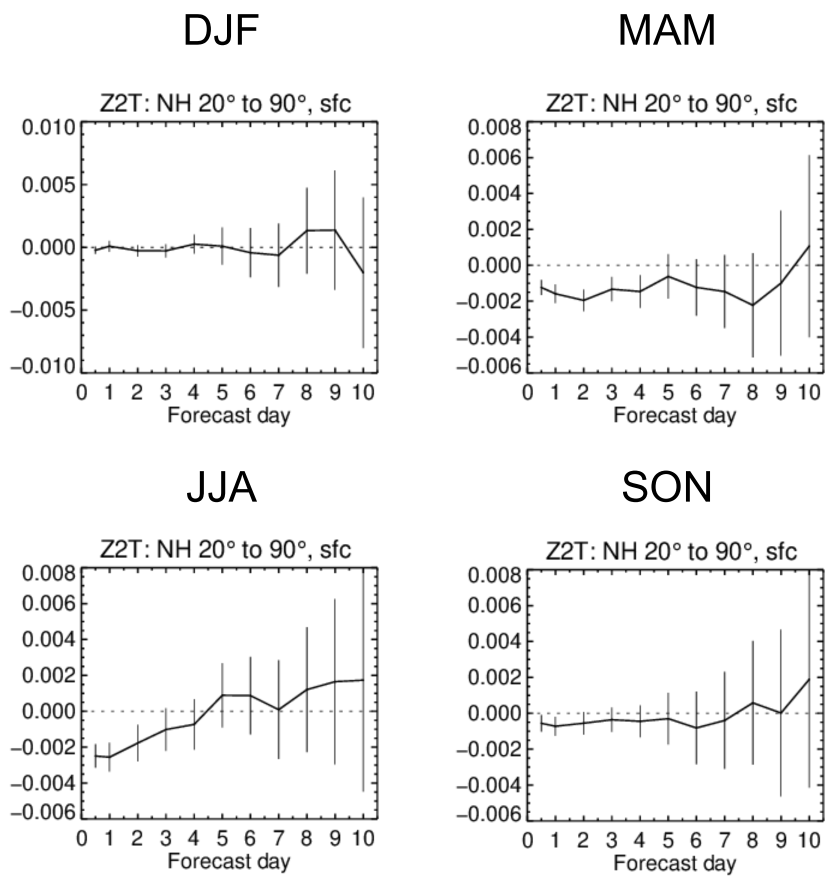




NWP results

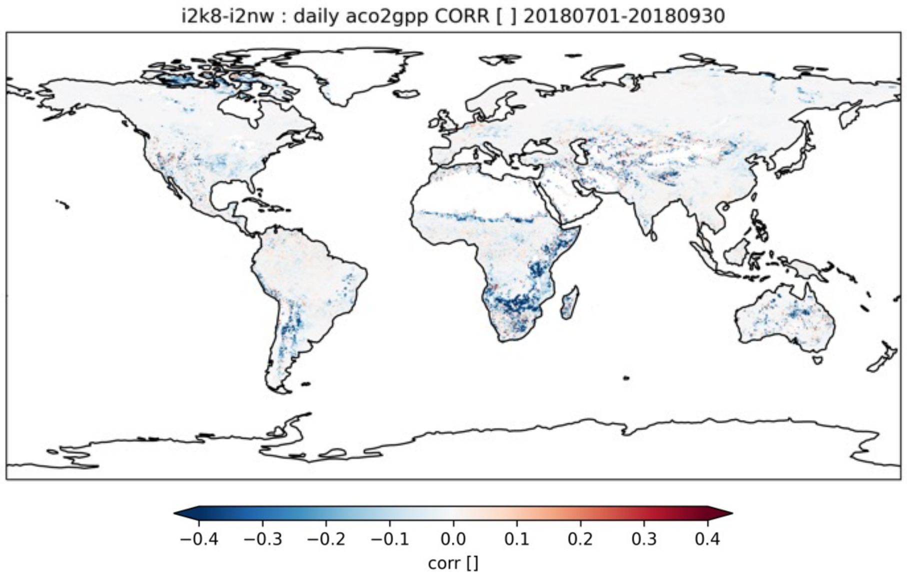
- In the Northern hemisphere largest impact in spring and summer
  - Most active vegetation-atmosphere coupling
  - Many observations screened out in frozen conditions in winter
- Smaller seasonal variations in Tropics
- Small impacts in the Southern hemisphere and only significant in DJF
- Results similar for L-, C- and X-band assimilation
  - All VOD bands CDF-matched to same LAI dataset

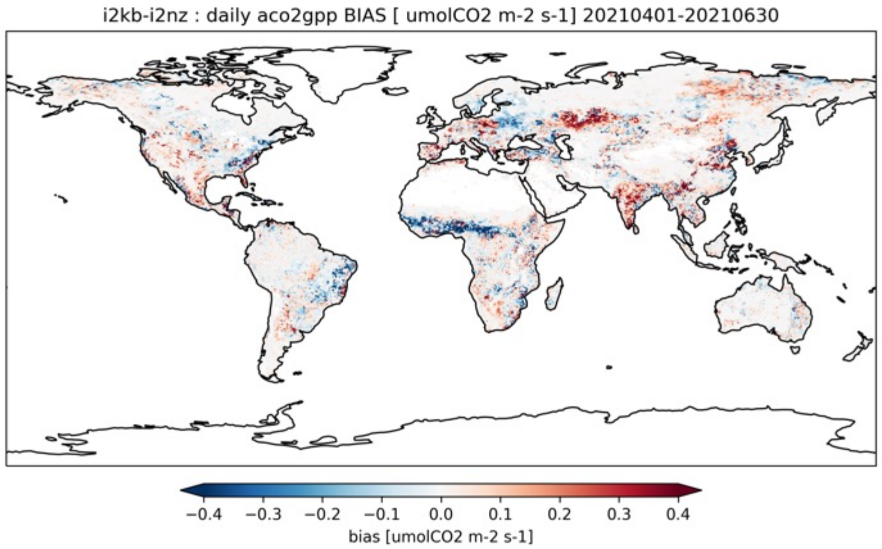




Carbon cycle results

- Small and mixed impact on the carbon cycle when verified against FLUXCOM gross primary production (GPP) observations
- Negligible changes in the global budgets – CDF-matching results in very small global bias changes
- Larger local changes
  - Reduced correlations, especially over Southern Africa
  - Mixed bias impacts, e.g. reduced biases over tropical Africa; increased biases over Asia





Conclusions

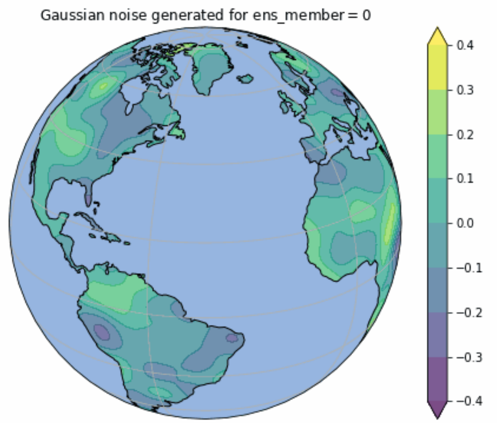
- Analysis increments and changes against climatology look reasonable

- NWP benefits from representation of inter-annual variations in vegetation
  - Improvements to surface and lower tropospheric temperature and humidity forecasts
  - Correction of systematic errors leading to significant reduction in mean forecast errors
  - Seasonal variation in impacts – largest impacts in local summer (extra-tropics)
  - Different VOD bands have similar impact

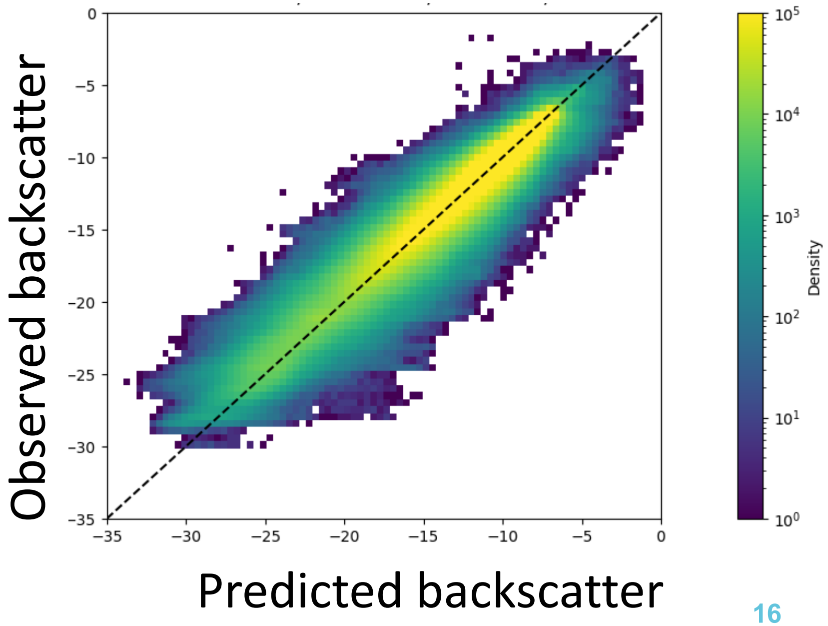
- Slight degradations in carbon cycle diagnostics
  - Compensating biases
  - Small global mean changes due to CDF-matching approach
  - Potential inconsistency between soil moisture and vegetation due to no correlations between vegetation and soil moisture

Future Work

- In contrast to this study, at ECMWF our aim is to assimilate level 1 observations where possible
  - Allowing multiple variables to be analysed consistently and simultaneously
- This requires accurate observation operators to simulate the observations from model variables
- Ongoing relevant work at ECMWF
  - Ewan Pinnington (CERISE): Development of perturbations to vegetation parameters to boost near-surface spread
  - Sebastien Garrigues (CORSO): Machine learning based observation operator development for low frequency microwave data (e.g. ASCAT, AMSR2) and solar induced fluorescence
  - Siham El Garroussi: Development of a VOD observation operator for fire applications
  - Souhail Boussetta: General move to more dynamic LAI in the IFS



Test: R^2=0.93; RMSE=0.87;MAE=0.78;SD=0.87



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THANK YOU

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