"MULTIPLY
Exploiting Benefits of Multi-sensor Synergies for EO Applications“
For addressing current global problems

2019-10-10

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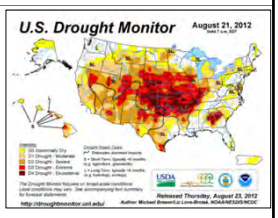
Rational: monitoring global environmental change

Fisher, J.B., et al., *The future of evapotranspiration: Global requirements for ecosystem functioning, carbon and climate feedbacks, agricultural management, and water resources.* Water Resources Research, 2017. **53**(4): p. 2618-2626.

- ‘The Future of Evapotranspiration’ (Fisher et al 2017), illustrating the importance of Evapotranspiration
  - Failing adequate characterization of the 2012 US Drought.
- Caused by knowledge gaps:
  1. How are ecosystems responding to changes in climate and water availability?
  2. How much water do plant assemblages use and how much do they need?
  3. What is the timing of water use, and how does that vary temporally?
  4. How plant water stress and availability regulate photosynthesis and productivity?
  5. How is ET partitioned into transpiration, soil evaporation.
  6. Can ET observations improve short-term prediction and future climate projections
- Shortcomings in current ET
  - Dependency Variables: LST, LAI, albedo, U, Ta, …..
  - Too dependent on a singular sensor.
  - Inconsistency between input variables -> large uncertainty



Timmermans et al, in review, Towards Satisfying Future Evapotranspiration Requirements

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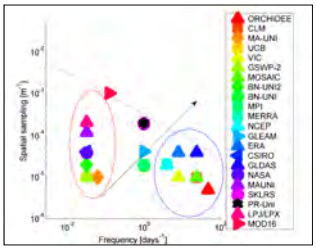
2

Rational: Trend in RS Applications

Fisher, J.B., et al., *The future of evapotranspiration: Global requirements for ecosystem functioning, carbon and climate feedbacks, agricultural management, and water resources.* Water Resources Research, 2017. **53**(4): p. 2618-2626.

- (Future) Applications demand
  - Higher resolution information (**10-100m,)**
  - Higher frequency information (**diurnal frequency)**
  - Lower (quantified) uncertainties (< **10%)**
- RS offers
  - Moderate increases in spatial resolution
  - Moderate increases in temporal frequency
  - Increasing number of satellites
  - Higher number of sensor types
  - Higher diversity of sensors
  - High model complexity
- RS fails to provide
  - Consistent data integration
  - Higher applicability
  - Higher level of understanding



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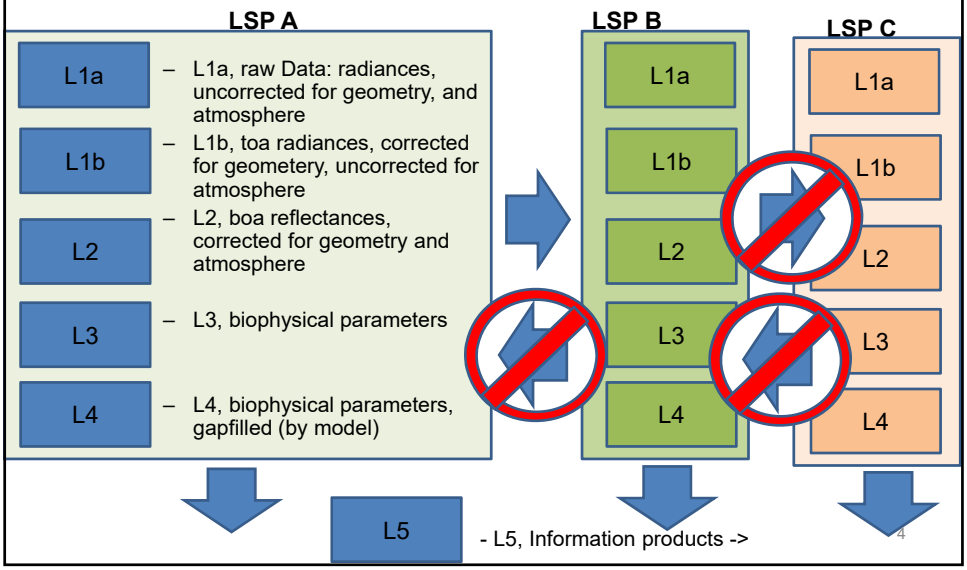
Moving away from the tradiational RS paradigm



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Data engineering: MULTIPLY: A complementary approach

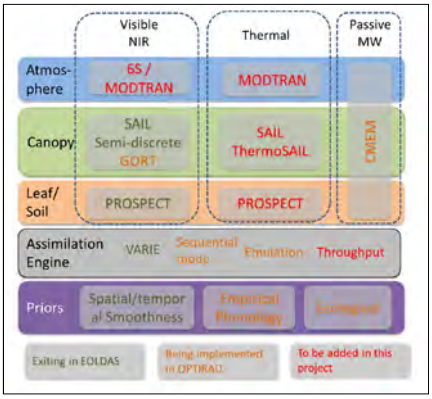
- To "*develop and enable application of a practical, flexible, user-friendly platform to provide the scientific community with a tool to generate **consistent** land surface products and its associated **uncertainties** and exploit these for **data-intensive science***"

- Bayesian Data Assimilation System
  - TOC/TOA observations
  - Improving Illposed problem
    - Prior-information
    - Temporal regularization
    - RT models (emulated versions)

$$J(x) = J_{prior}(x) + J_{obs}(x) + J_{model}(x)$$

- Multi-Satellite
  - High res SAR (Sentinel 1)
  - High res Optical (Sentinel 2 Landsat)
  - Med. Res Optical (Sentinel 3, MODIS)

- On basis of EOLDAS but with focus on
  - Optical and SAR coupling
  - Ecosystems
  - Operational service provision



Lewis et al (2012), The *Earth Observation Land Data Assimilation System*

Chernetskiy et al, 2017, Earth Observation Land Data Assimilation System (EO-LDAS) Regularization Constraints over Barrax Site

Gomez-Dans et al, (2016), Efficient Emulation of Radiative Transfer Codes Using Gaussian Processes and Application to Land Surface Parameter Inferences

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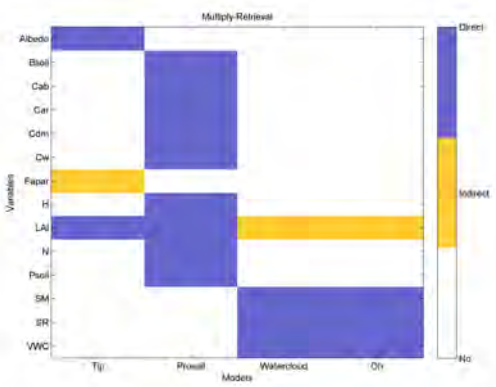
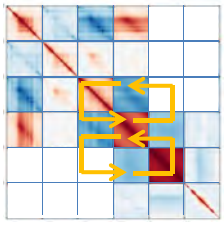
Data engineering: Define state to ensure consistency

- Variable selection (on basis of global sensitivity analysis)
  - Defining synergies
  - Uncoupled/ Coupled variables
    - Defined for singular/multiple forward operator

$$J(x) = J_{prior}(x) + J_{obs}(x) + J_{model}(x)$$





State Variables:
Optical only: Leaf Contents (Cab, Cdm)
SAR only: soil moisture, soil texture
Coupled Variable: LAI, (water content)

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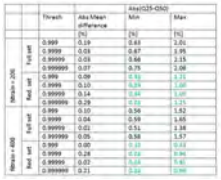
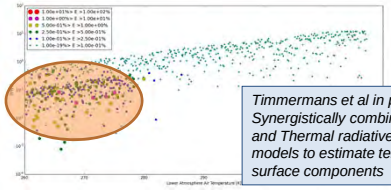
Data engineering: Computational & Machine Learning concepts

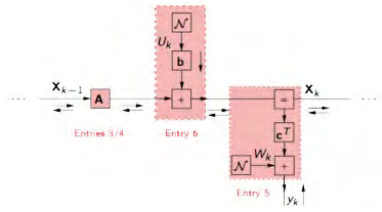
- Training Gaussian Process & Neural Network emulators on the radiative transfer models as forward operators
  - Evaluation of emulators using generalized cross validation.

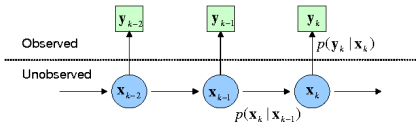




Timmermans et al in preperation, Synergistically combining Optical and Thermal radiative transfer models to estimate temperature of surface components

- Apply Transformation to the state-variables to linearize the inference-problem
- Evaluation of solvers





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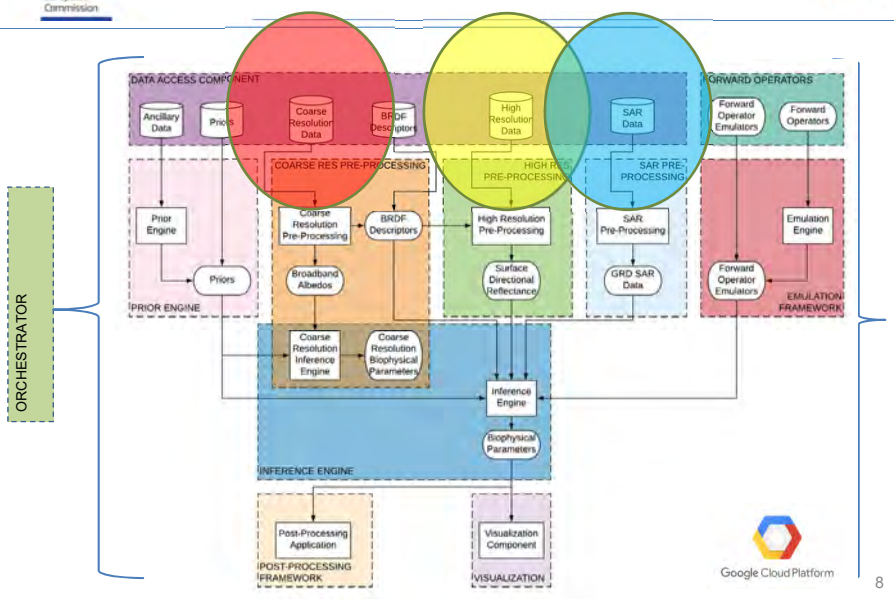
Data engineering: The MULTIPLY Platform



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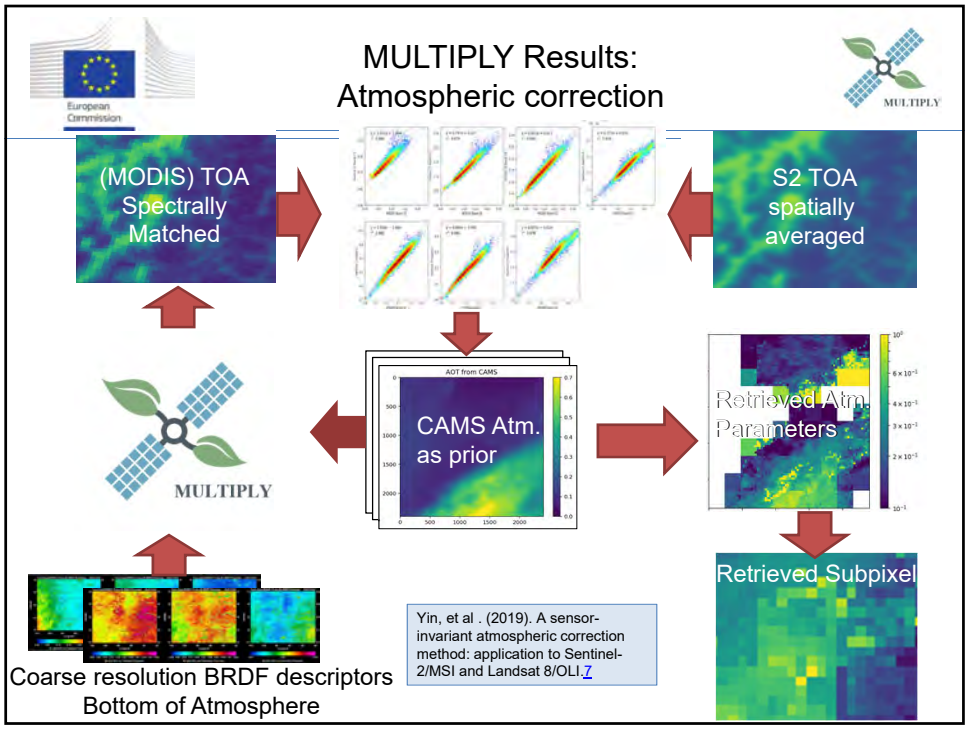
MULTIPLY Results:
Atmospheric correction
(MODIS) TOA Spectrally Matched
S2 TOA spatially averaged
CAMS Atm. as prior
Retrieved Atm. Parameters
Retrieved Subpixel
MULTIPLY
Coarse resolution BRDF descriptors
Bottom of Atmosphere
Yin, et al . (2019). A sensor-invariant atmospheric correction method: application to Sentinel-2/MSI and Landsat 8/OLI.7

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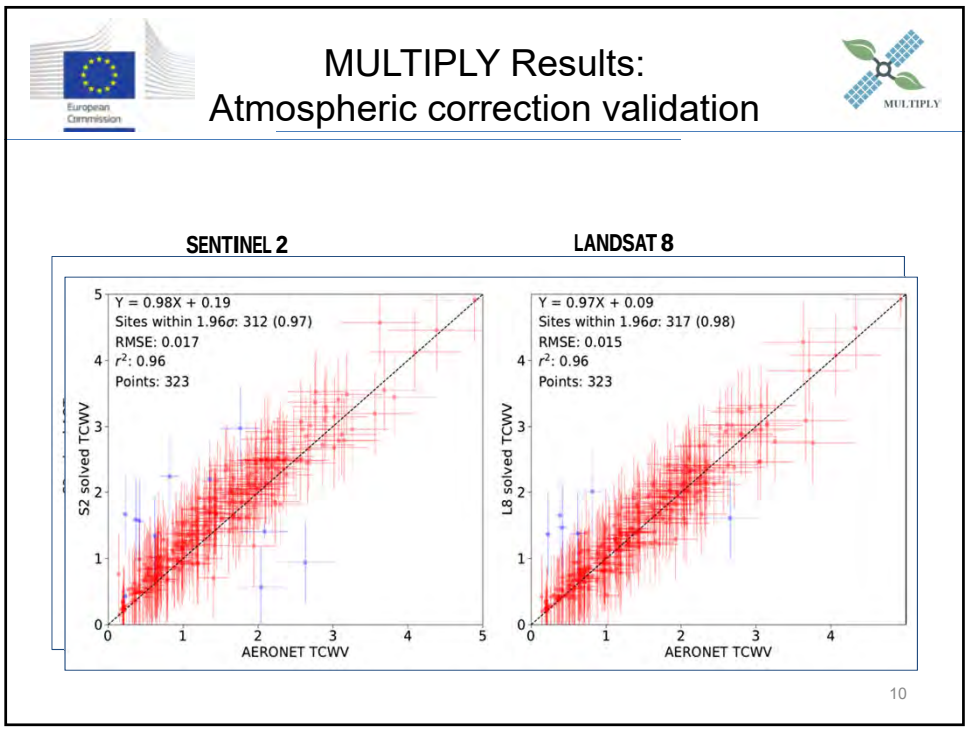
MULTIPLY Results:
Atmospheric correction validation
SENTINEL 2
LANDSAT 8
Y = 0.98X + 0.19
Sites within 1.96σ: 312 (0.97)
RMSE: 0.017
r²: 0.96
Points: 323
S2 solved TCWV
AERONET TCWV
Y = 0.97X + 0.09
Sites within 1.96σ: 317 (0.98)
RMSE: 0.015
r²: 0.96
Points: 323
L8 solved TCWV
AERONET TCWV
10

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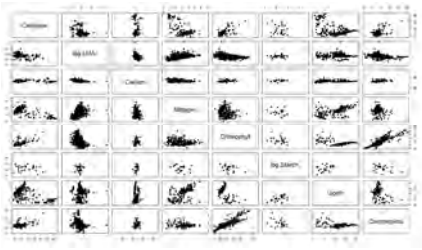
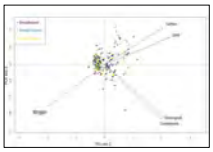
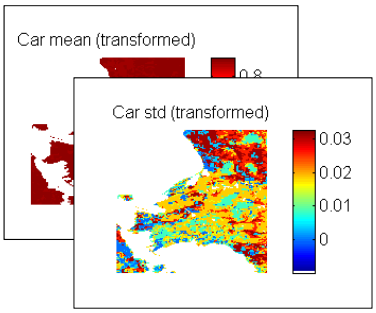
MULTIPLY Results: Creating Ecological Relevent Prior Information

- Analysis of TRY database
  - Showing decoupling between Nitrogen and Chlorophyll.
- Global Modelling
  - Mapping distribution Plant functional groups







Corbin et al. In preparation, Towards improving land vegetation surface parameter retrieval in the MULTIPLY data assimilation platform with plant trait databases

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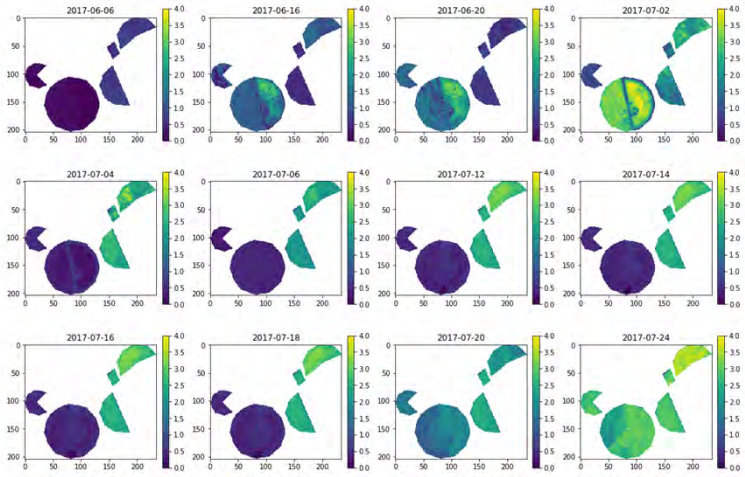
MULTIPLY Results: Retrieving land surface parameter time series

LAI time series at Barrax



Google Cloud Platform

jupyterhub

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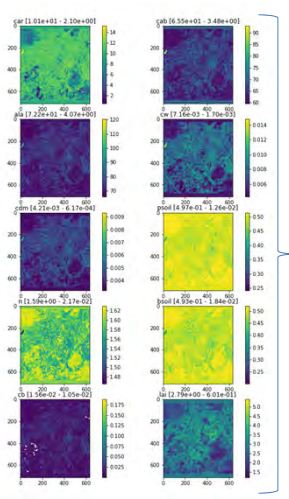
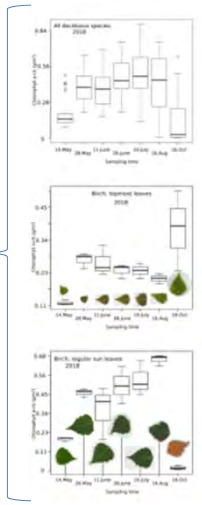
MULTIPLY Results: Validating Retrieval

- Currently ongoing, Jarvselja Observatory, Estonia





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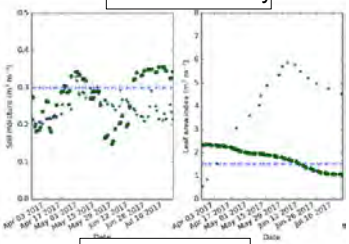
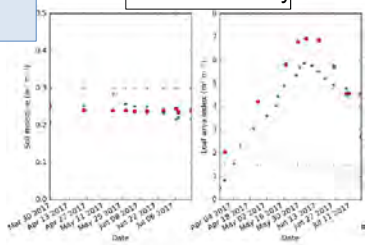
Initial MULTIPLY Results: fusion Optical and SAR observations

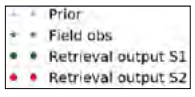
Quaife et al, in preparation, Retrieving Agricultural land surface parameters from joint usage of sentinel-1 and 2 observations.

Sentinel 1 only

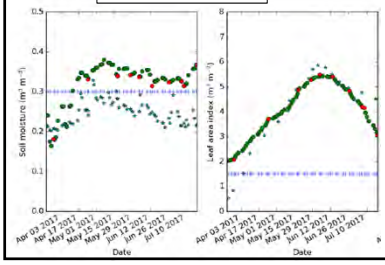


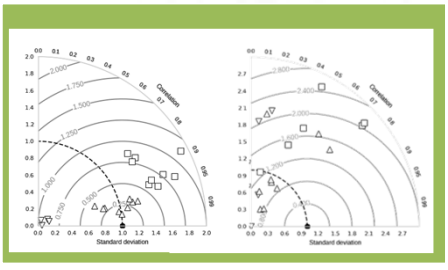
Sentinel 2 only





Sentinel 1 & 2





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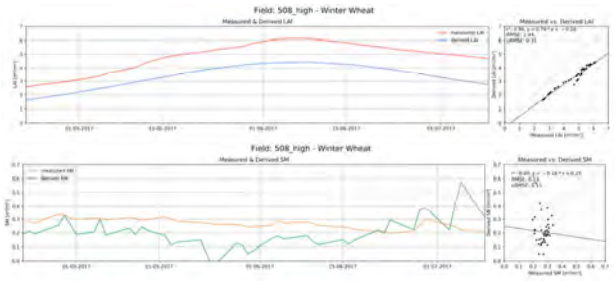
Updated MULTIPLY Results: fusion Optical and SAR observations

- Currently implemented in the system (last week)



- Further testing/validation currently performed

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Conclusions

An operational **version (optical only)** **of** MULTIPLY is ready for use (sign up required). This features

- Automatic atmospheric correction through use Synergistic of coarse and high resolution sensors
- Complete inference of emulated forward operators to functional traits.
- Integration of additional prior ecological information for contraining inference problem.
- Quantification of Uncertainty through error-propagation

Synergistic retrieval **(of optical and SAR)** of MULTIPLY is undergoing testing and validation (to be finished before 20 October 2019). Featuring

- Consistent definitions of state variables / radiative processes
- Synergistic use of observations to advance: #observations and uncertainties

We aim to use **test cases** to establish those links.

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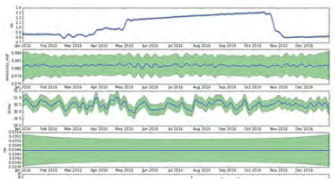
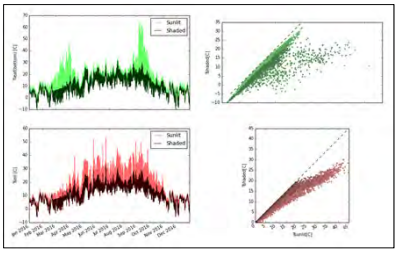
Outlook: Embedding thermal observations

- For drought monitoring still additional parameters are required (namely Land surface temperature)
- Potential of Optical and Thermal observations (in ESA Sentinel Synergy project) to estimate soil and vegetation temperatures at high resolution





Timmermans et al in preperation, Synergistically combining Optical and Thermal radiative transfer models to estimate temperature of surface components

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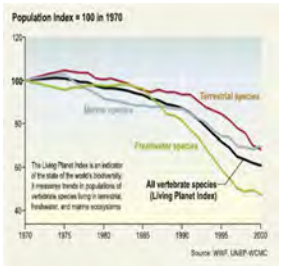
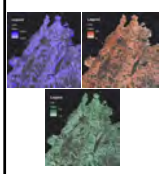
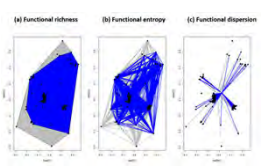
Outlook: monitoring global Biodiversity decline

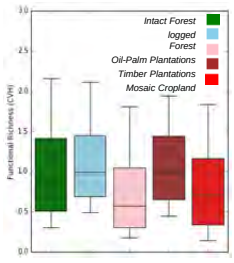
(2019) IPBES Global Assessment Report on Biodiversity and Ecosystem Services

- Biodiversity loss is a global phenomenon, (The Living Planet Index),
  - In-situ measured
  - Focus on species
- Satellite Remote sensing
  - Global coverage at various scales
  - Functional traits of vegetation
  - Statistical analysis of **multiple RS products**
    - Chlorophyll, Water Content, Dry matter, ….









Hauser et al, Mapping functional diversity across different land-use types using satellite earth observation, in review in Nature Geosciences

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ADAS
iLab
Google Cloud Platform
esa European Space Agency

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Thank you!

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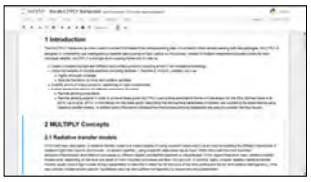
Documentation
https://multiply.readthedocs.io/

Currently Deployed on Google Compute Engine
http://multiply-platform.eu



Google Cloud Platform

More information
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