OGS 2022

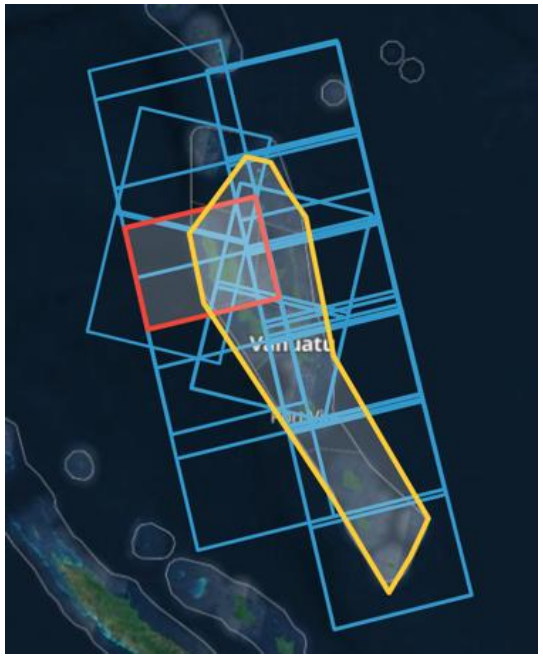
Pacific Community
Communauté du Pacifique

Digital Earth PACIFIC

Public-Good Cloud-Native Earth Observation Infrastructure for the Region (Technical Session)

Sachindra Singh
Pacific Community (SPC)

What is DIGITAL EARTH PACIFIC?



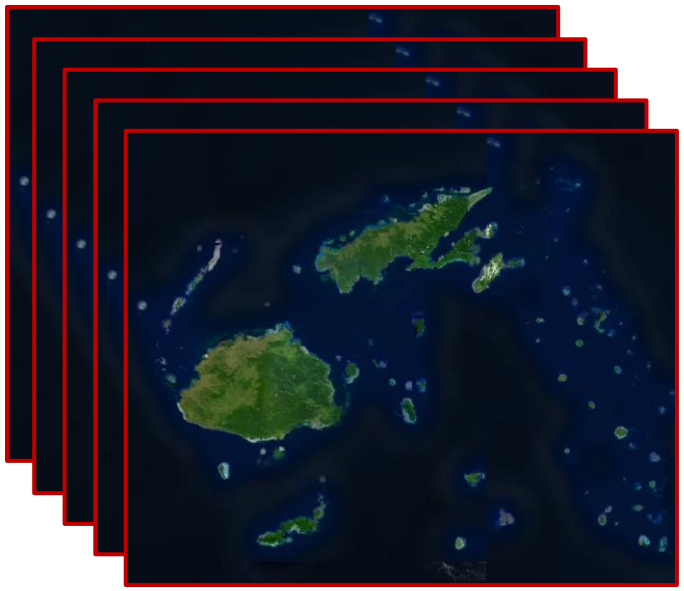
The Digital Earth Pacific project supports the development of an operational earth observation system that takes decades of freely available data and brings it together in a sensible way within the Pacific context. It will allow SPC's **26** Member States to make more informed decisions based on good information to overcome the challenges we face such as climate change, food security and disasters.

This solution will help us understand the changes in our environment such as the impact sea-level rise has on our communities, planning for disaster preparedness, response and recovery, and productivity of agricultural fields and potential impacts by changes in weather.

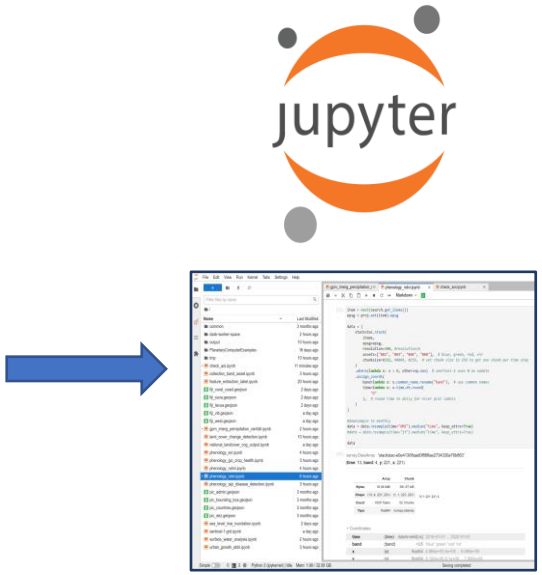
Leveraging this technology will allow the development of decision-ready products that will support concise and analysed information for decision makers whilst providing needed data and information to support regional and global commitments such as the 2050 Strategy for the Blue Pacific Continent, the Paris Agreement or the Sustainable Development Goals.

DEP in a (technical) nutshell

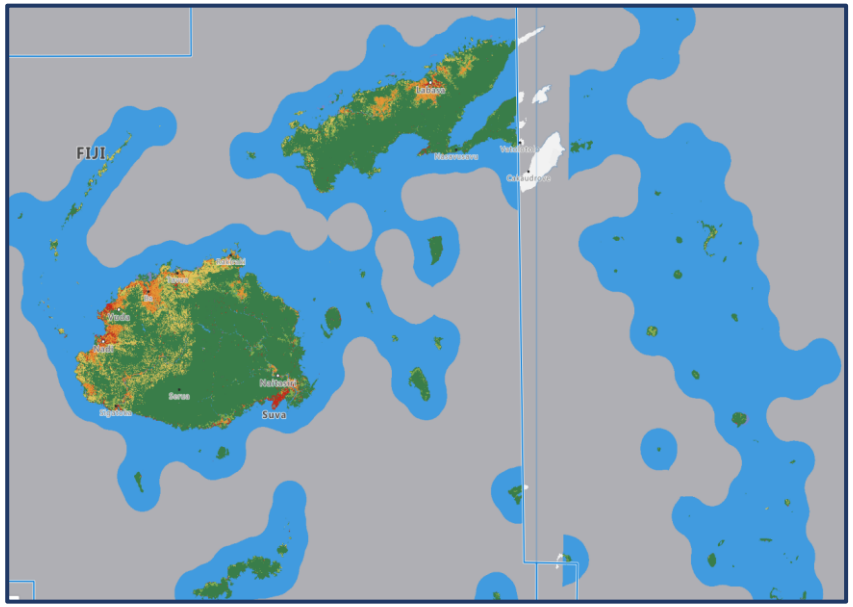
Digital Earth Pacific is an **analytical geospatial cloud-native** platform that makes remotely-sensed analysis ready data (ARD) accessible* via well-defined standards ; and enables users to perform highly scalable EO tempo-spatial analysis* using open source data science libraries and models.



Multi-spectral Satellite Data

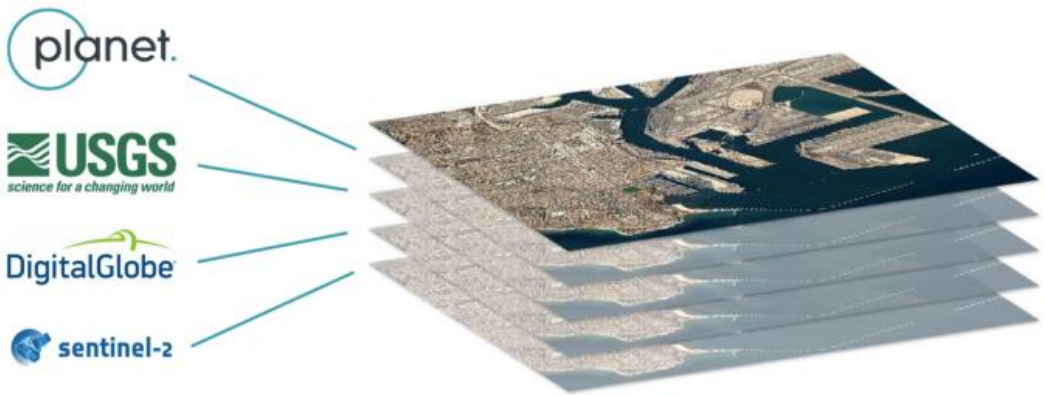


Notebooks are RESUABLE components that combines live code, visualisations, documentation and configurations to enable EO analysis at scale.



Earth Observation Product

Analysis Ready EO Data



Analysis Ready Data are time-series stacks of overhead imagery that are prepared for a user to analyse without having to pre-process the imagery themselves.

Satellite data that have been processed to a minimum set of requirements and organized into a form that allows immediate analysis with a minimum of additional user effort and interoperability both through time and with other datasets.

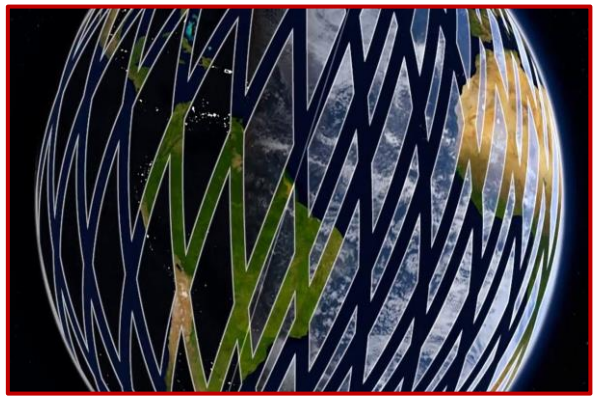
Those who don't work with satellite imagery every day likely underestimate the amount of labour involved in preparing imagery for analysis.

Major data providers such as ESA Copernicus Program, NASA/USGS Landsat Program, now enable and provision analysis ready data in cloud-optimised formats.

Analysis Ready Data Sources

Constellation	No. Satellites	No. Multispectral Bands	Resolution	Year	Revisit Cycle
Landsat 8	1	11	30m/pixel	2013-	16 days
Sentinel 2	2 (a/b)	13	10m/pixel	2015-	6 days
Sentinel 1	2	SAR (Radar)	5-20m/swath	2014-	12 days
Examples of Models					
Copernicus DEM/NASA DEM			30m/pixel	2019-	
Terra-Climate Model				1958 -	
NASA IMERG Precipitation Model				2000 -	

- Sentinel 2 - RGB, Vegetation Edge, Water Vapour, Near Infra-Red
- Landsat 8 - RGB, Near Infra-Red, Panchromatic, Thermal, Coastal Aerosol
- Sentinel 1 - SAR/Radar Data (Penetrates Cloud)
- *Sentinel 3 - Oceans, Meteorological Observations*
- *Sentinel 6 – Sea Level Rise, Ocean Observations (2020-) * (Not yet used within DEP)*



Acquisition Challenges in Pacific

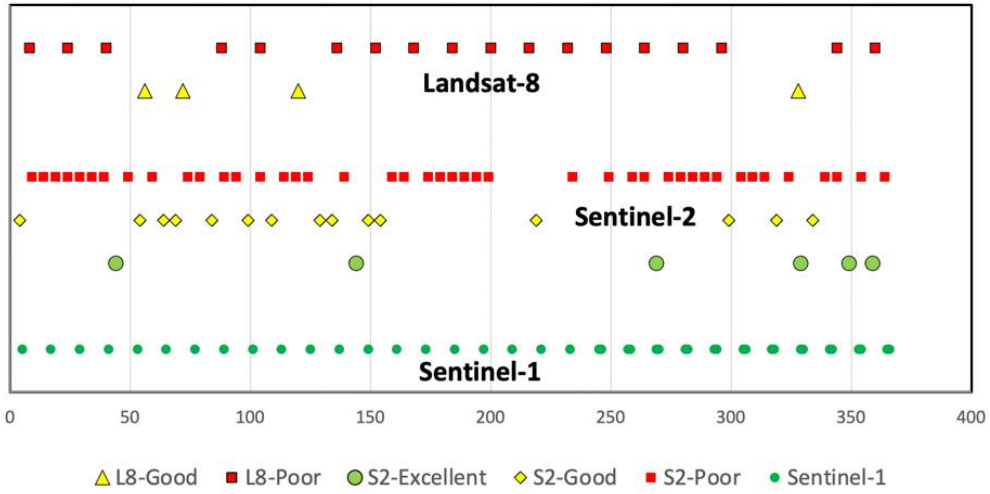


Table 4: Availability of Landsat 8 and Sentinels 1 and 2 satellite data across Pacific countries and territories

Country	Landsat-8	Sentinel-2	Sentinel-1
American Samoa	Yes	Both	1A
Cook Islands	Yes	Both	No
Fiji	Yes	Both	Both
French Polynesia	Yes	Both (mix North/East)	Both (few regions)
Guam	Yes	Both	No
Kiribati	Yes	Both	No
Marshall Islands	Yes	Both	No
Micronesia	Yes	Both	No
Nauru	Yes	Both	No
New Caledonia	Yes	Both	1B
Niue	Yes	Both	No
Northern Mariana Islands	Yes	Both (South only)	No
Palau	Yes	Both	No
Papue New Guinea	Yes	Both	Both
Pitcairn Islands	Yes	Both	No
Solomon Islands	Yes	Both	1B
Samoa	Yes	Both	1A
Tokelau	Yes	No	No
Tonga	Yes	Both	No
Tuvalu	Yes	Both	No
Vanuatu	Yes	Both	Both
Wallis and Futuna	Yes	Both	No

- Cloud cover is a major problem (only few months of useable imagery for major islands in some cases)
- SAR/Radar acquisition not enabled for open seas (eg: critical for applications such as vessel tracking, oil spill detection)
- Resolution (=> 10m/px) is not always suitable for change analysis in atoll scenarios (eg: coastline change detection)
- Lack of analytical capabilities, specialised software/hardware for large-scale analysis of tempo-spatial data within PIC Govts; especially for continuous monitoring.
- GEO-PIAG is ideally placed to *"lobby"* for solutions: eg: Pacific ground receiving station for Copernicus Constellation, strengthening engagement with JAXA, Gaofen etc.

DEP Options Explored

Open Data Cube	Google Earth Engine	Microsoft Planetary Computer
Used by Digital Earth Australia, Digital Earth Africa, and Pacific Common Sensing Project	Primarily used in Academia, Methodology Prototyping	Newest implementation with evolving users
Data pipelines, injestion and storage of open ARD from satellite vendors managed by users on own cloud resources and infrastructure. (Costly for regional deployments)	Data pipelines and storage managed by Google on GCP	Data pipelines, injestion and storage of open ARD from satellite vendors managed by Microsoft team on Azure Platform
Wasn't designed and built with STAC compliance. Currently interfaces being developed and retro-fitted	Non-STAC Compliant	Designed and built on STAC industry standard.
Uses common EO data science libraries and API, along with custom built interfaces (odc-tools, odc.algo, odc.io, odc.stats)	Google-created non-standard data structures and data libraries used (JS, Python)	Uses standard and interopable EO data science libraries and API. (Dask, Xarray, StackStac, PyStac, Pangeo Community)
Can incorporate custom large-scale institutional data eg: imagery, models etc	Not easy to incorporate large-scale institutional data	Can host and incorporate custom large-scale institutional data eg: imagery, models etc in MSPC Hub

SpatioTemporal Asset Catalog (STAC) specification provides a common language to describe a range of geospatial information, so it can more easily be indexed and discovered. Enables reuse of data across different satellite data providers, EO products platforms. Important for sustainability, conformance and "future proofiness" of EO products and outputs, no vendor lock-in.

DEP Implementation - MSPC

The Microsoft Planetary Computer (MSPC) is a platform that lets users leverage the power of the cloud to accelerate environmental sustainability and Earth science (first iteration released July 2021)

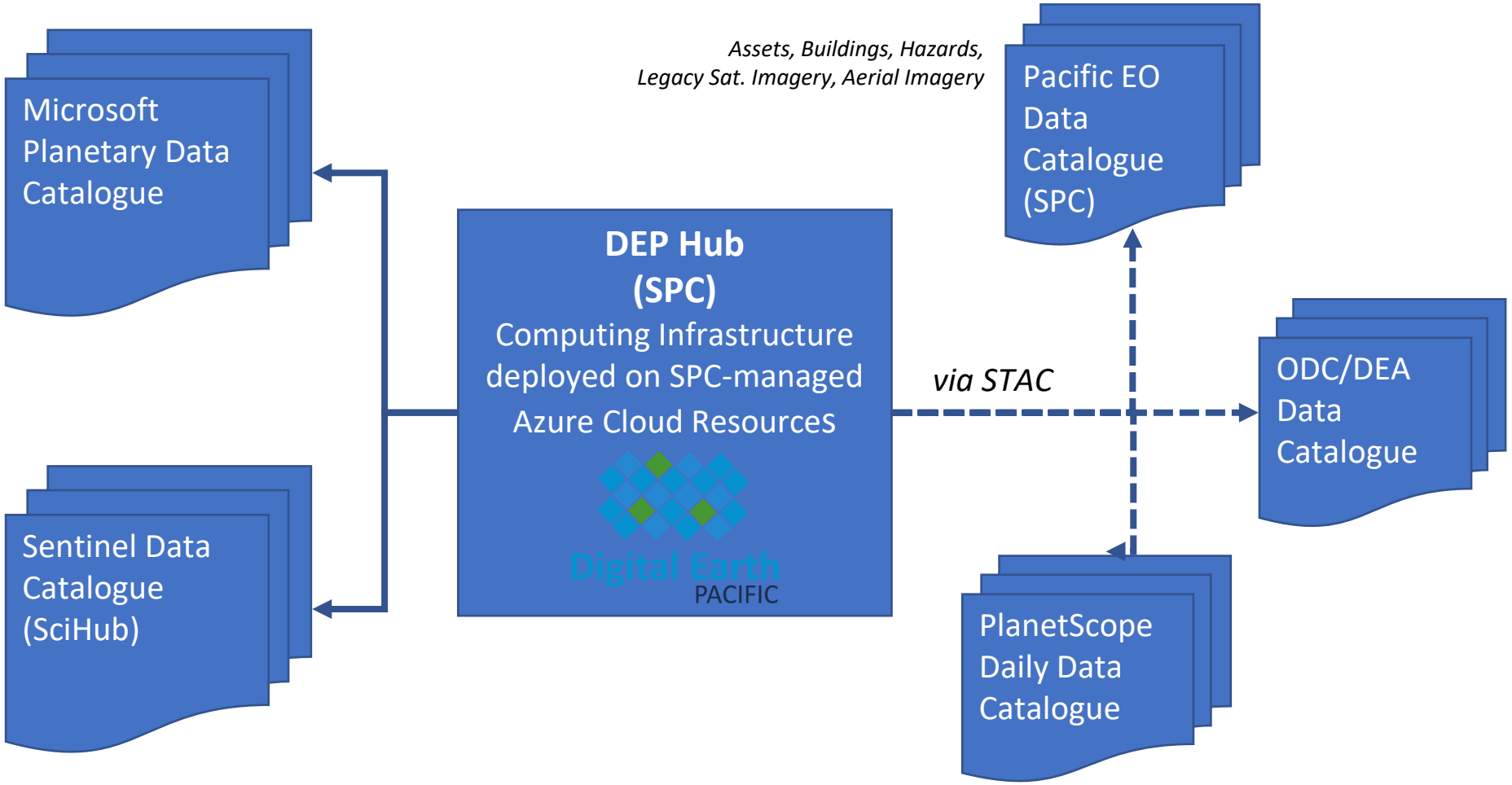
The Planetary Computer consists of 3 major components:

1. The Data Catalog - which includes petabytes of up-to-date and historical data about Earth systems.
2. Data Science Ecosystem – open libraries/API's that allow users to search for the data they need across space and time.
3. **The Hub - a computing environment that allows scientists to process/analyse massive geospatial datasets.**

Microsoft

DEP Infrastructure (What is DEP?)

Digital Earth Pacific is a SPC-owned and managed MSPC Computing Hub (Infrastructure), which enables Pacific Users to undertake analytics on Microsoft-managed Petabytes of Earth Observation data.



2020 – Project and Stakeholder Engagement Started

Jul 2021 - DEP Platform Selected

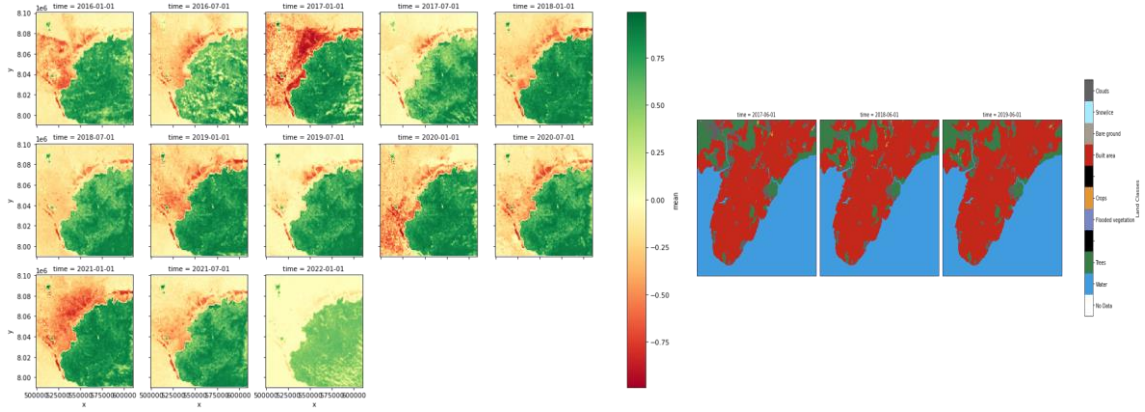
Dec 2021 - DEP Prototype Deployed

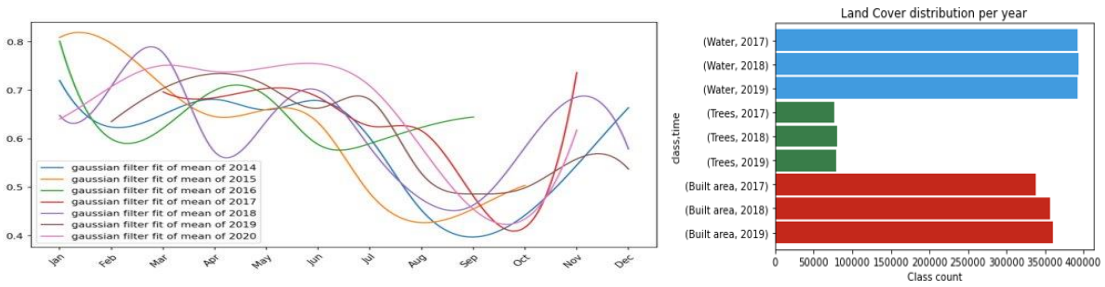
As of Feb 2022, DEP is the 1st and Only MSPC Hub deployed globally in a production setting, on SPC-owned and managed cloud resources on the Azure platform

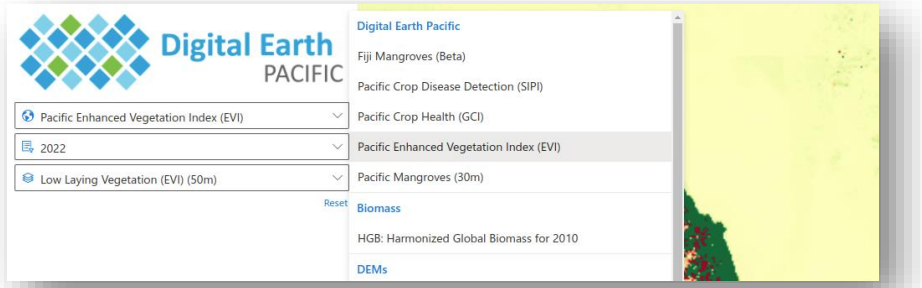
Future: STAC Interoperability with ODC (Digital Earth AU/Africa), Planet and SPC STAC Data Catalog.

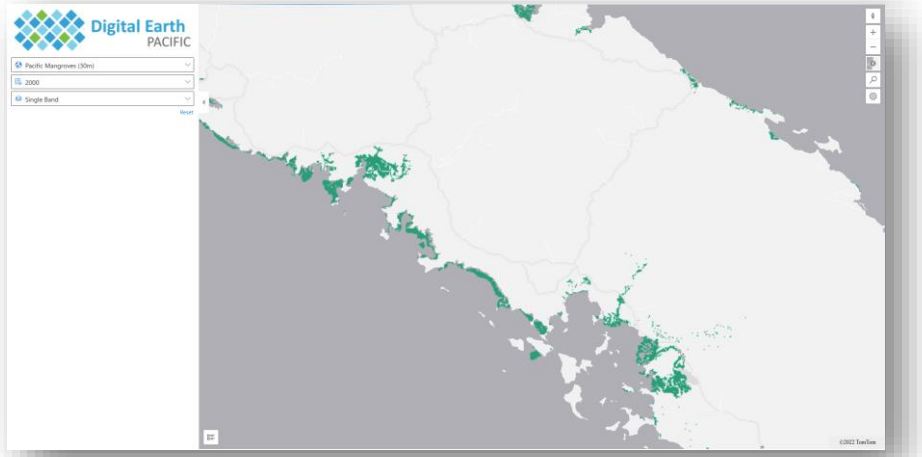
MVP Products (1)

Analytical Products	Explorer Products
Tempo-spatial analysis of EO data with imagery and charting outputs in notebook environment. Full-ledged products currently generated on smaller localised scale (vertical slices)	Scaled-out regional derived imagery products available for visualisation on the DEP Explorer instance. Not inclusive of charting and analytics, but outputs used for further analysis.









https://dep-pccompute.westeurope.cloudapp.azure.com/

https://explore.digitalearthpacific.org/

MVP Products (2)

Analytical Products	Initial Explorer Products
<u>Phenology Indicies</u> Low Laying Vegetation (EVI) Crop Health (GCI) Crop Disease Detection (SIPI) Mangroves/Non-Mangroves Change Detection	<u>Phenology Indicies</u> Low Laying Vegetation (EVI) Crop Health (GCI) Crop Disease Detection (SIPI) Mangroves/Non-Mangroves Change Detection
<u>Disasters and Water Security</u> Feature Extraction (Buildings, Roads) Annual Landcover Change Detection (ESA) Sea Level Rise Inundation Impacts Spatial Rainfall Analysis Surface Waterways Change Detection Flood Monitoring (SAR)	<u>*Work In Progress*</u> Near Shore Bathymetry (SAR) 90m Monthly Country-Specific Landcover (Atolls, Volcanic) Illegal River Extraction (FJ) Algae Bloom Monitoring (CK) Sea Surface Temperature (S3/S6) Sea Surface Heights (S3/S6) Mean Sea Level Pressure (S3/S6) Ocean Color et.al (S3/S6) Geological Features eg: Lithology (Hydrology) Geothermal Deposits (Hot Springs) (L8 OLI/TIRS)
<u>Oceans</u> Shoreline Extraction for Change Detection Near-shore Bathymetry (Optical) 6m	

Completed product notebooks are based on Tier 1 and Tier 2 priority cases from needs assessment workshops (Vanuatu, Fiji, Marshall Islands, Tonga)
https://github.com/PacificCommunity/DigitalEarthPacific

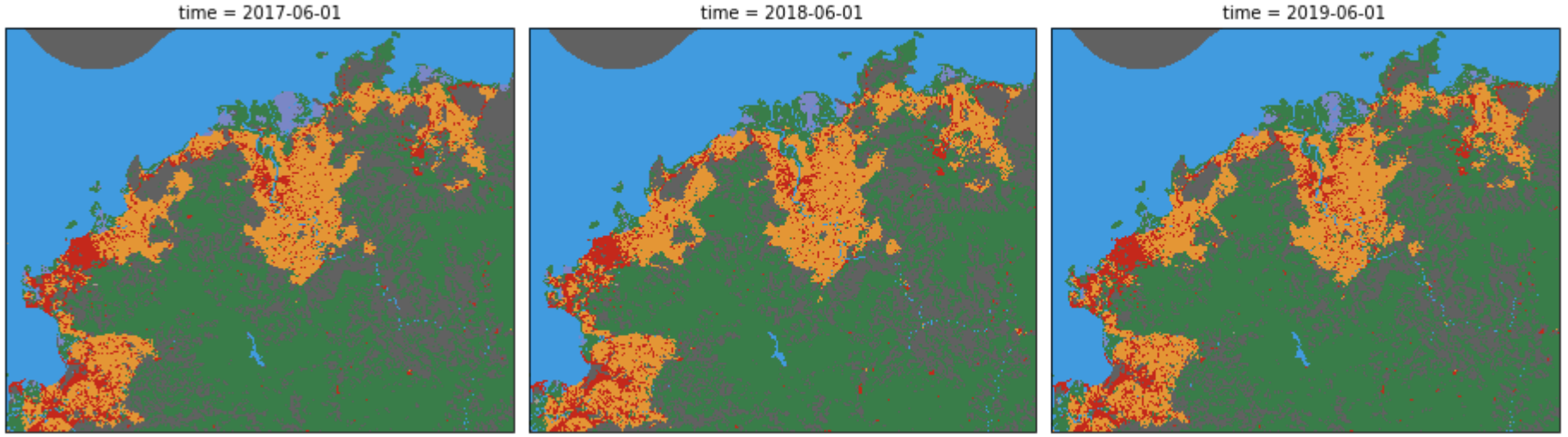
Product Development Disclaimer

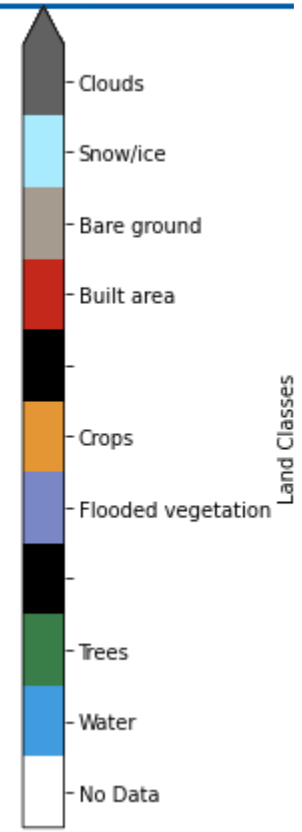
Based on DEP Needs Assessment Workshops: Tiers 1, 2, 3

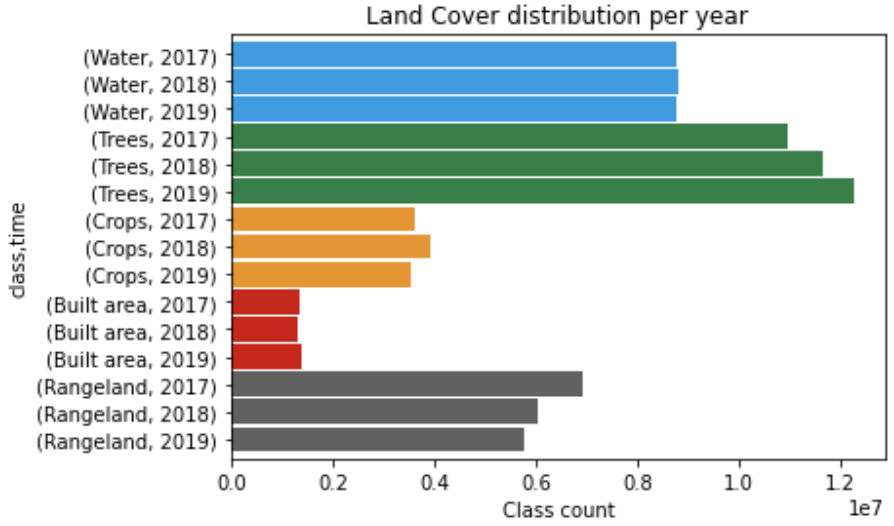
The data and information products within this presentation are derived through analysis of open earth observation and remotely sensed data within the Digital Earth Pacific (DEP) platform via code, machine learning algorithms and models that are still in active development.

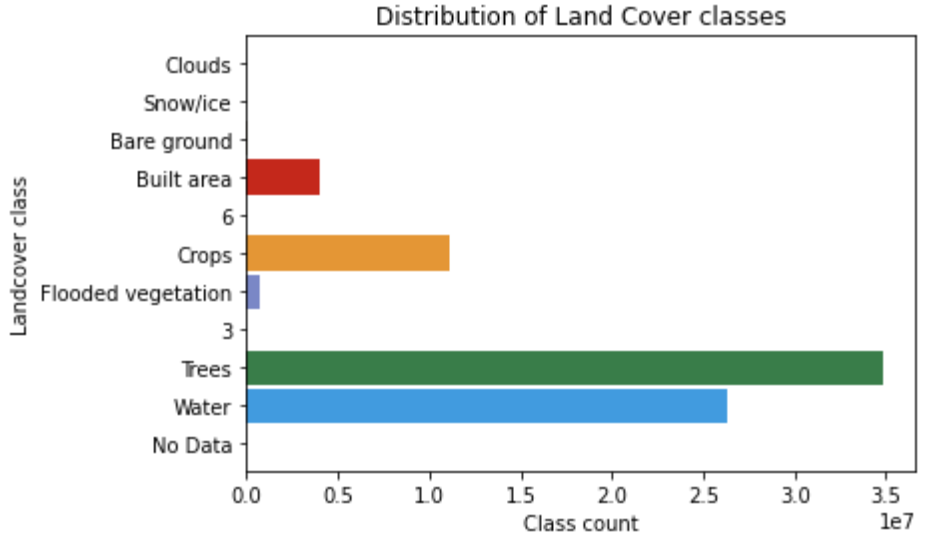
None of the products demonstrated herewith are official or have been validated via ground-truthing and/or field validation, and are presented here purely to demonstrate the analytical capabilities of the Digital Earth Pacific (DEP) platform.

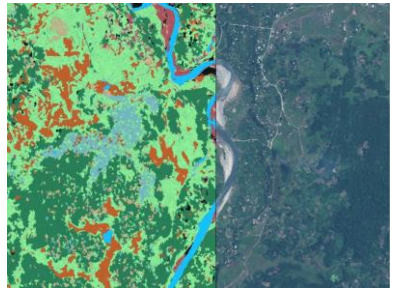
Land Cover Change Detection (1)



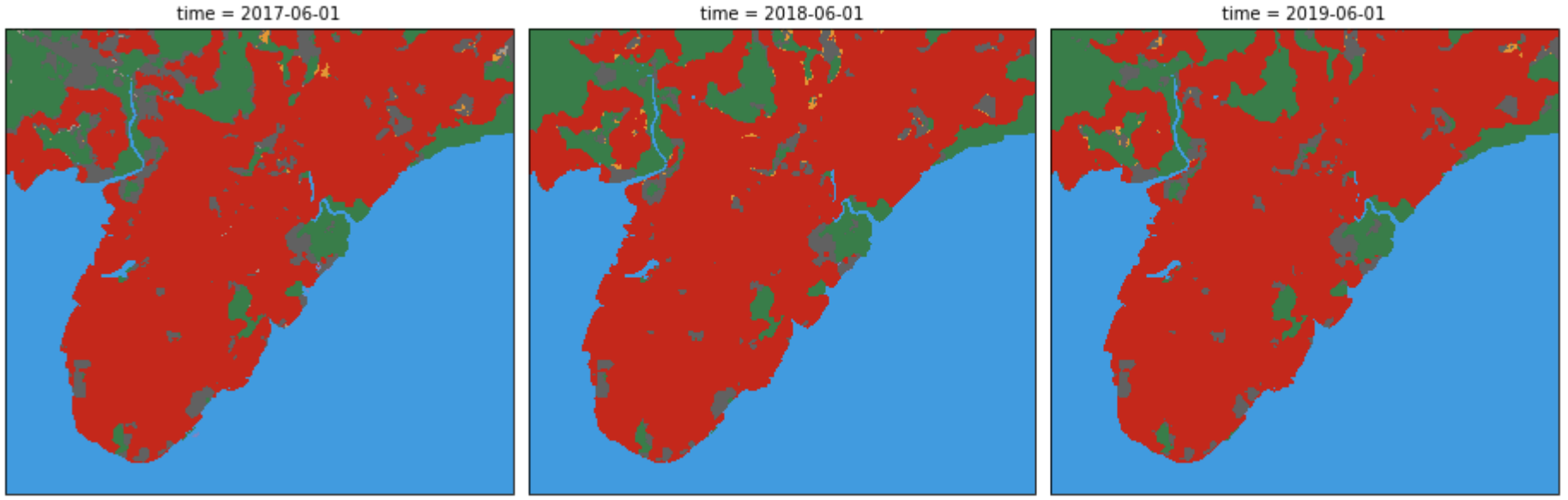


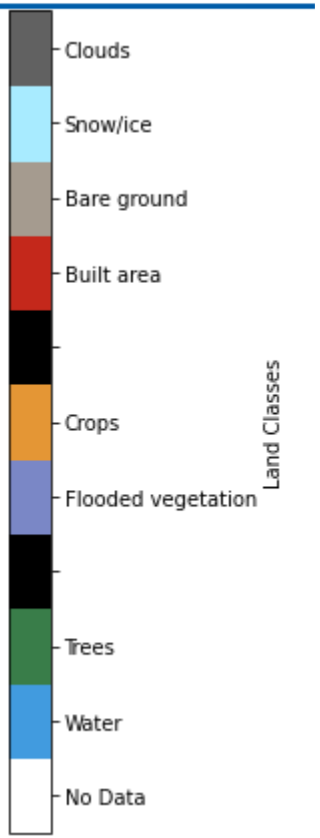


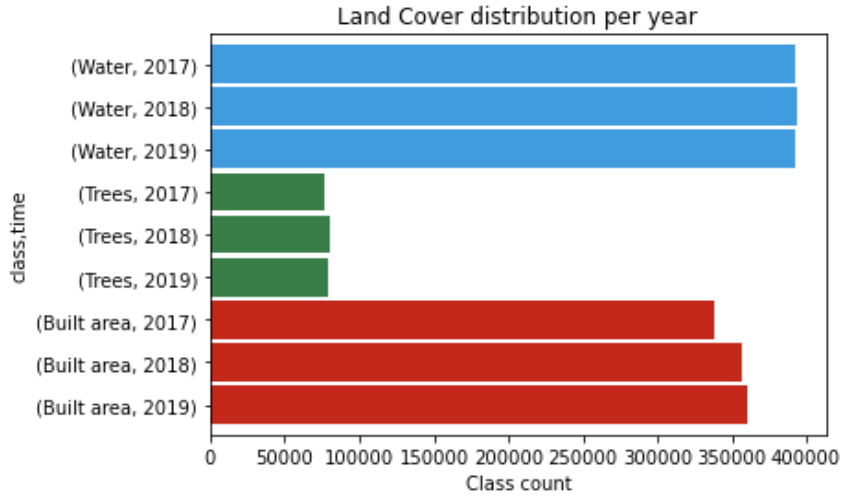


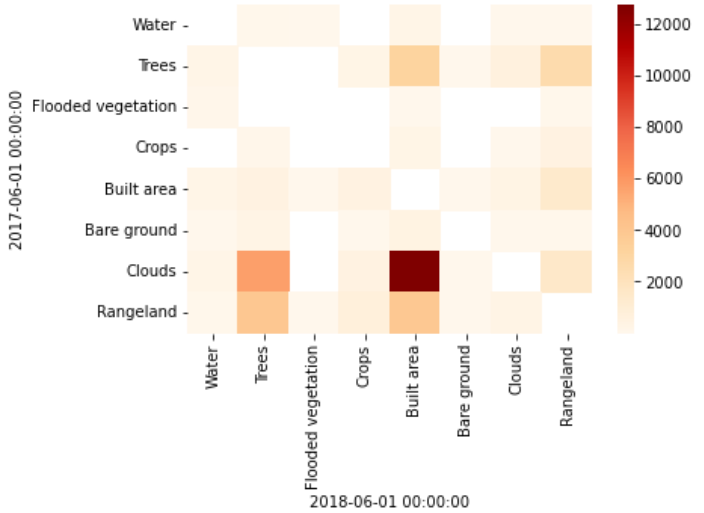


Land Cover Change Detection (2)



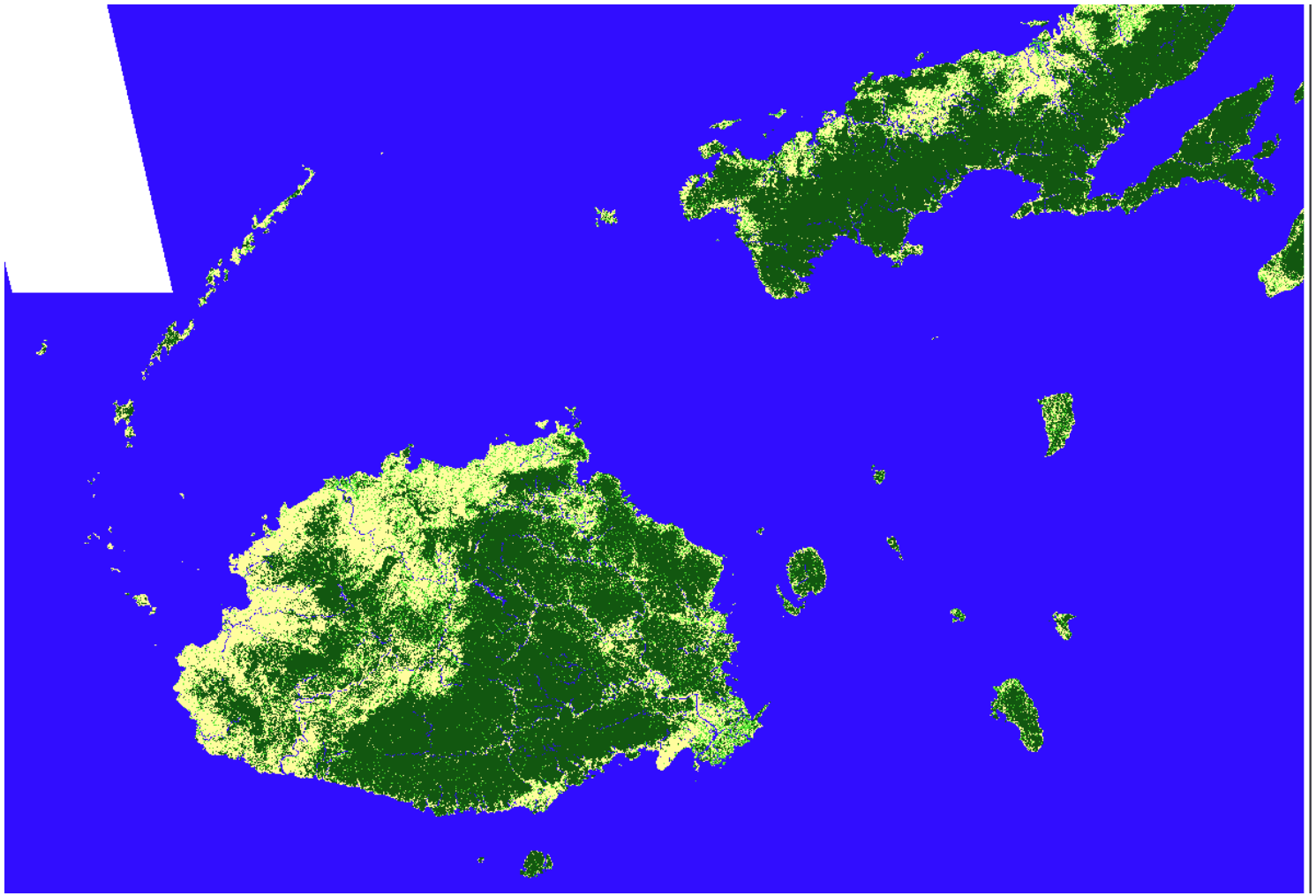


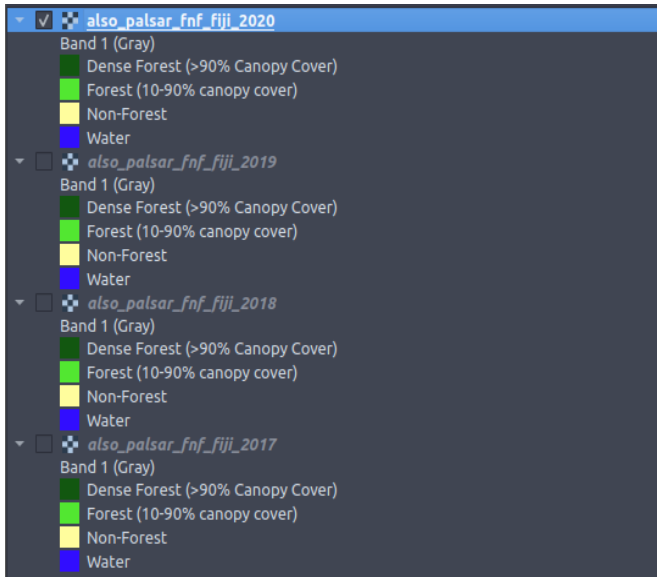


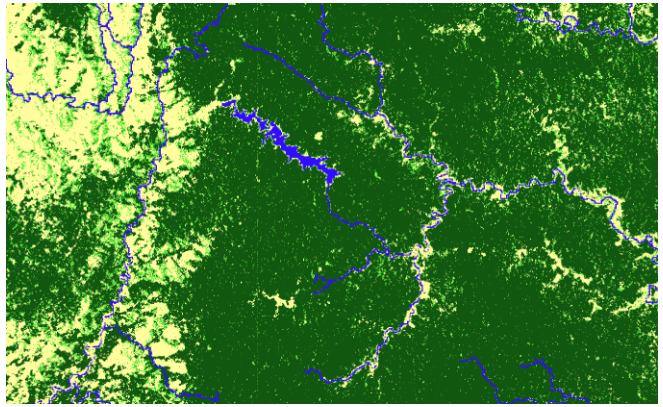


<u>Operationalisation</u>: Landcover Change Detection products generated fortnightly using co-registered S2/L8 imagery.

Land Cover Change Detection (3)

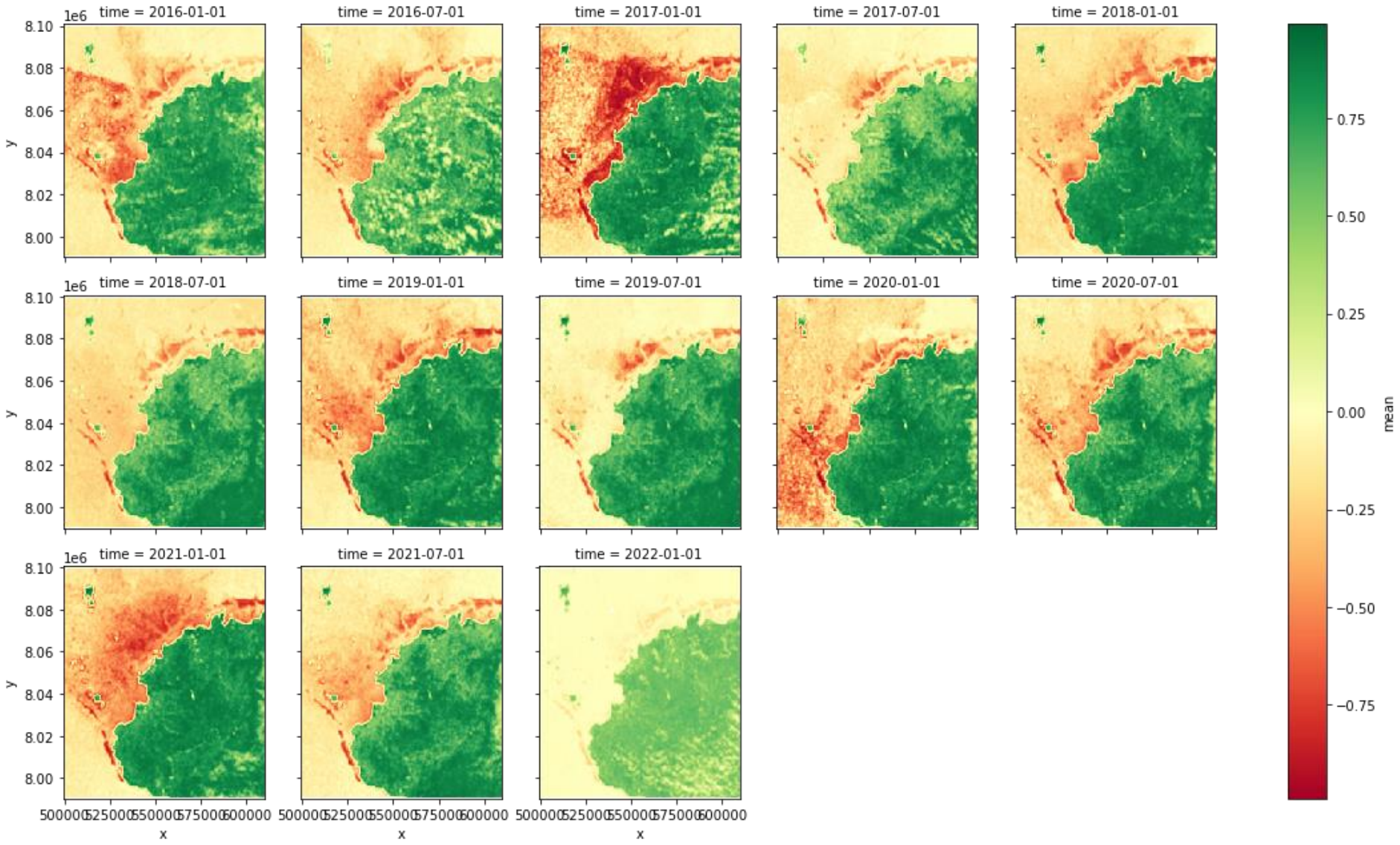






Work has started to update Landcover Maps for Fiji with Ministry of Lands. Baseline product (2017-) delivered derived from ALOS PALSAR Annual Mosaics.

Phenology: NDVI



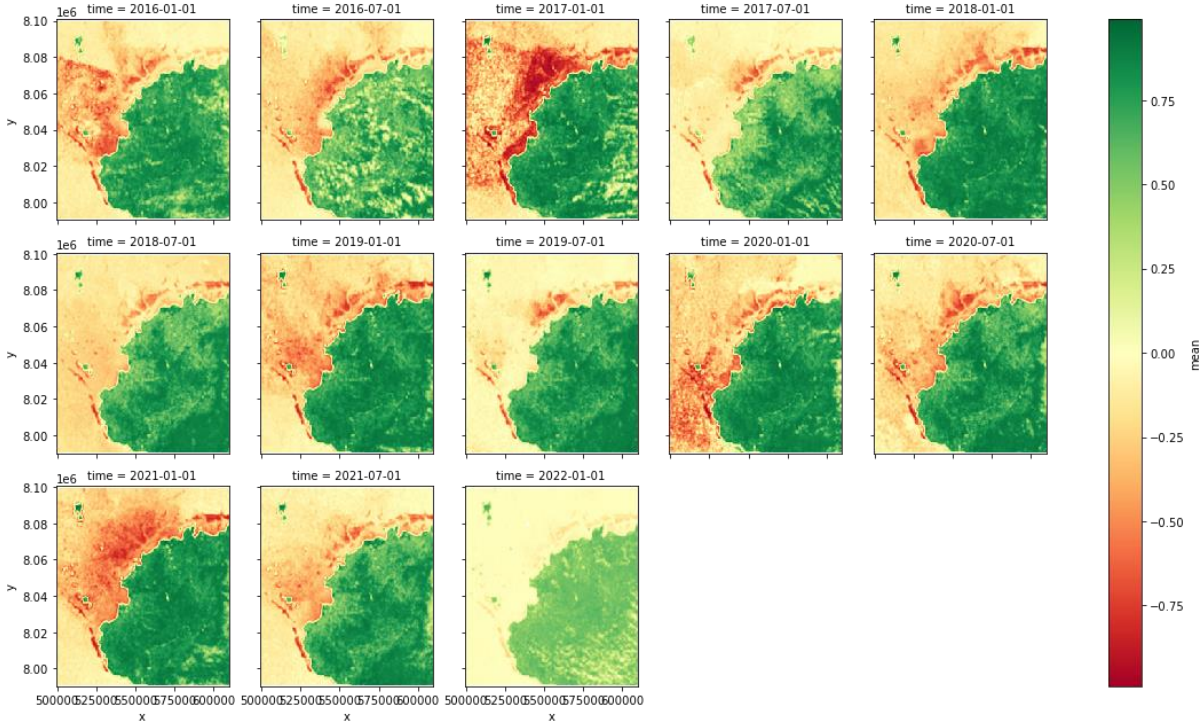
Computes **Normalized Difference Vegetation Index** (NDVI).

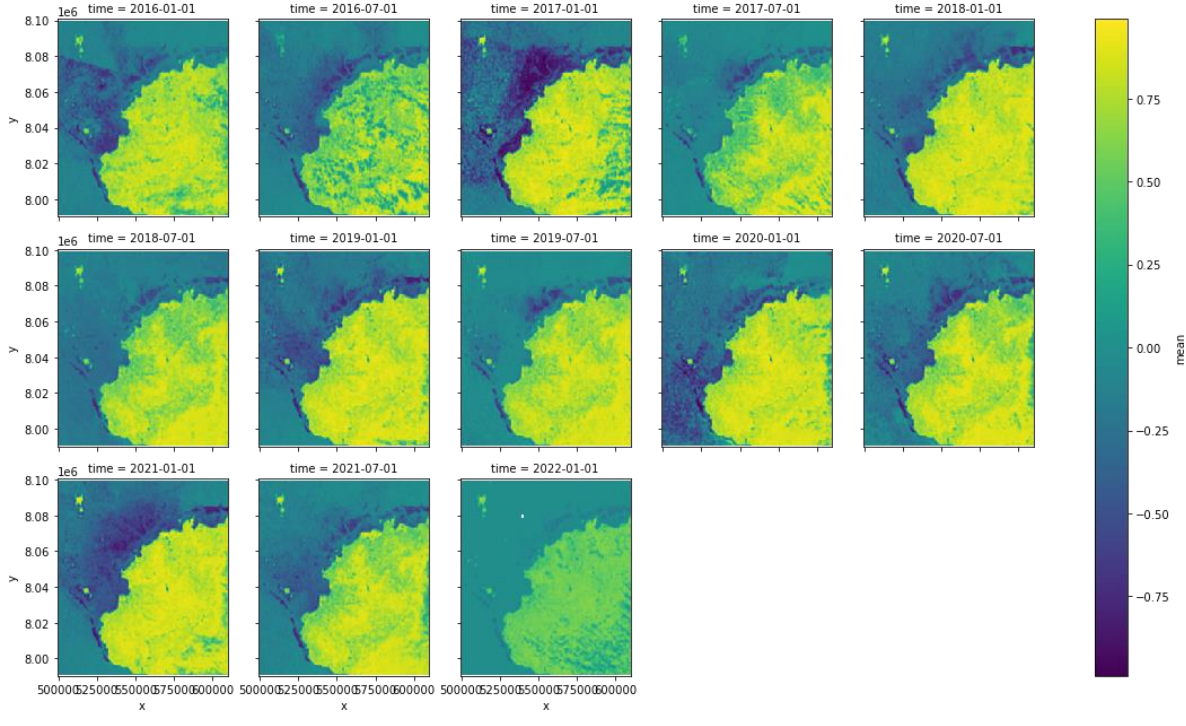
Used to determine if a cell contains live green vegetation.

Phenology: EVI

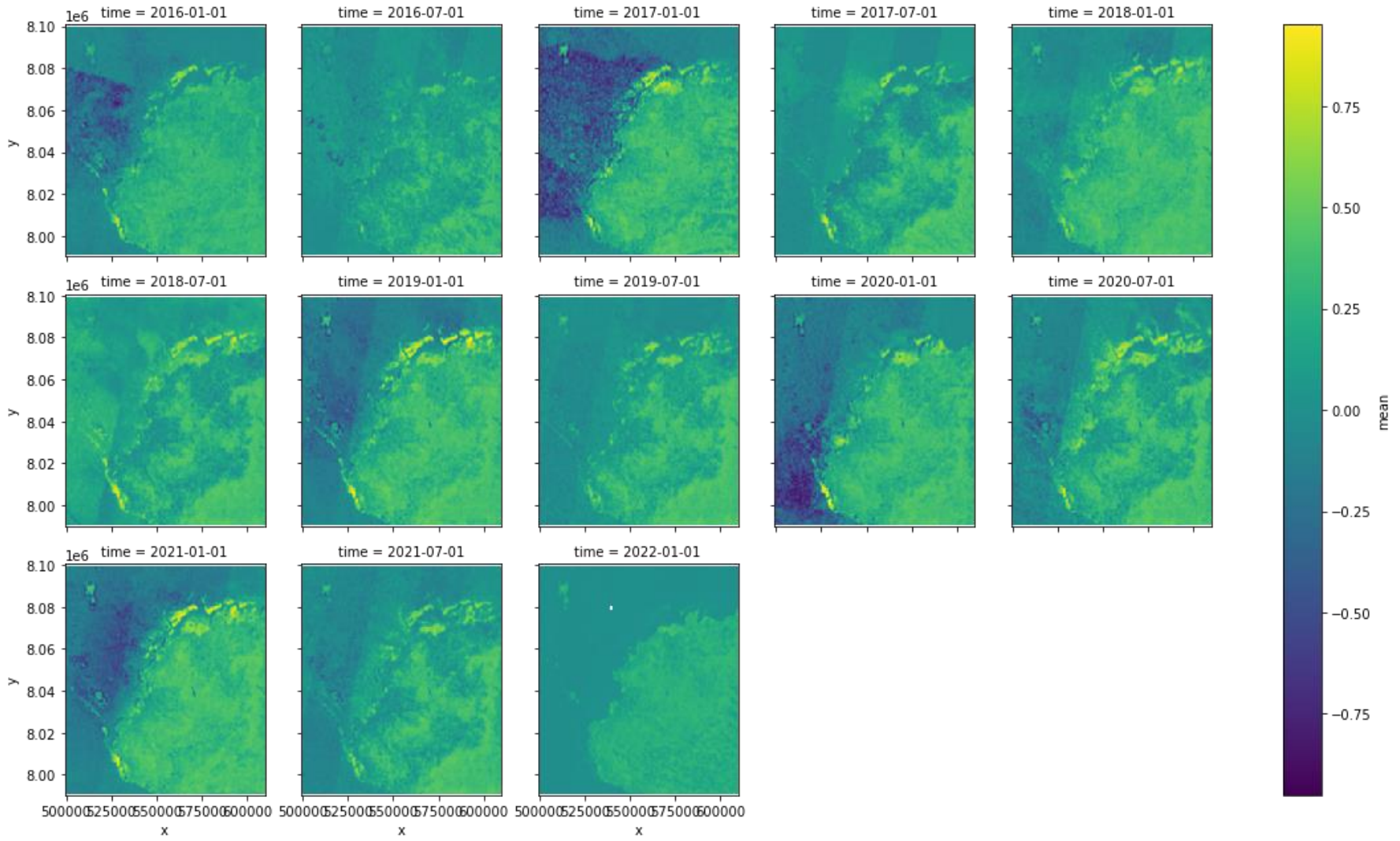
Computes **Enhanced Vegetation Index** (EVI). Allows for improved sensitivity in high biomass regions, de-coupling of the canopy background signal and reduction of atmospheric influences. Low-laying vegetation.

Used to identify stress related to drought over different landscapes. Mainly associated with the development of droughts affecting agriculture.





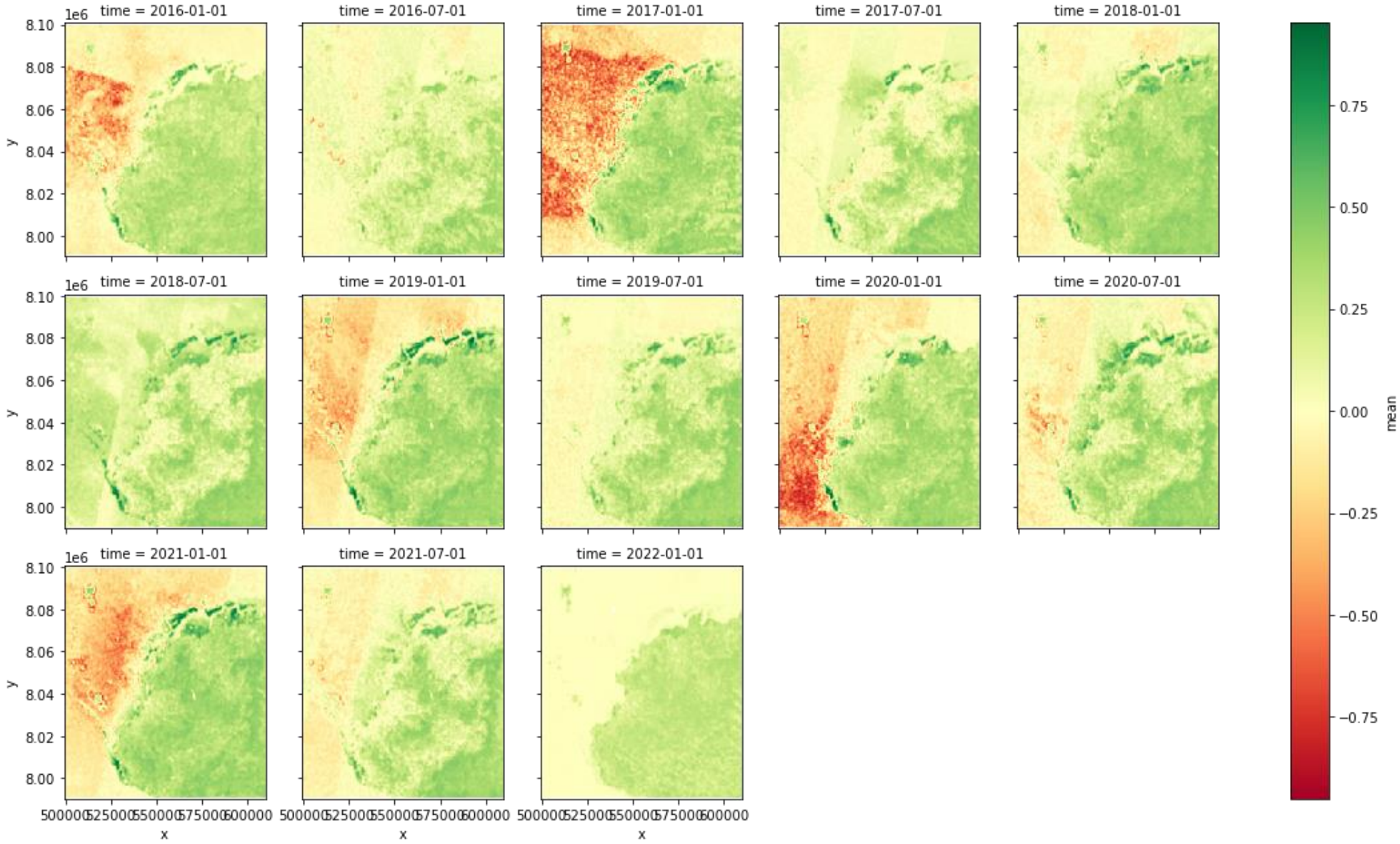
Phenology NDMI (1): Moisture



Computes Normalized Difference Moisture Index.

Used to determine vegetation water content. For drought monitoring.

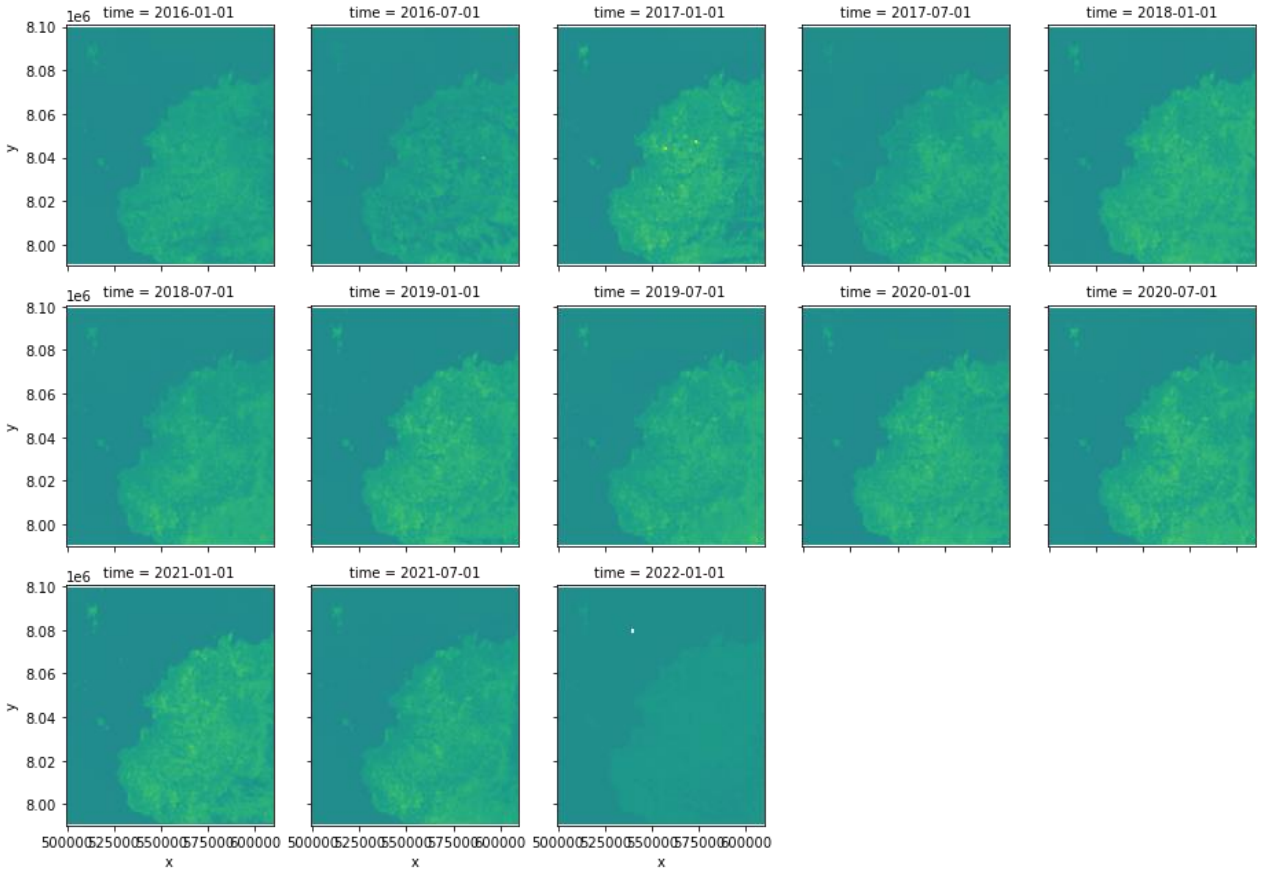
Phenology NDMI (2): Moisture

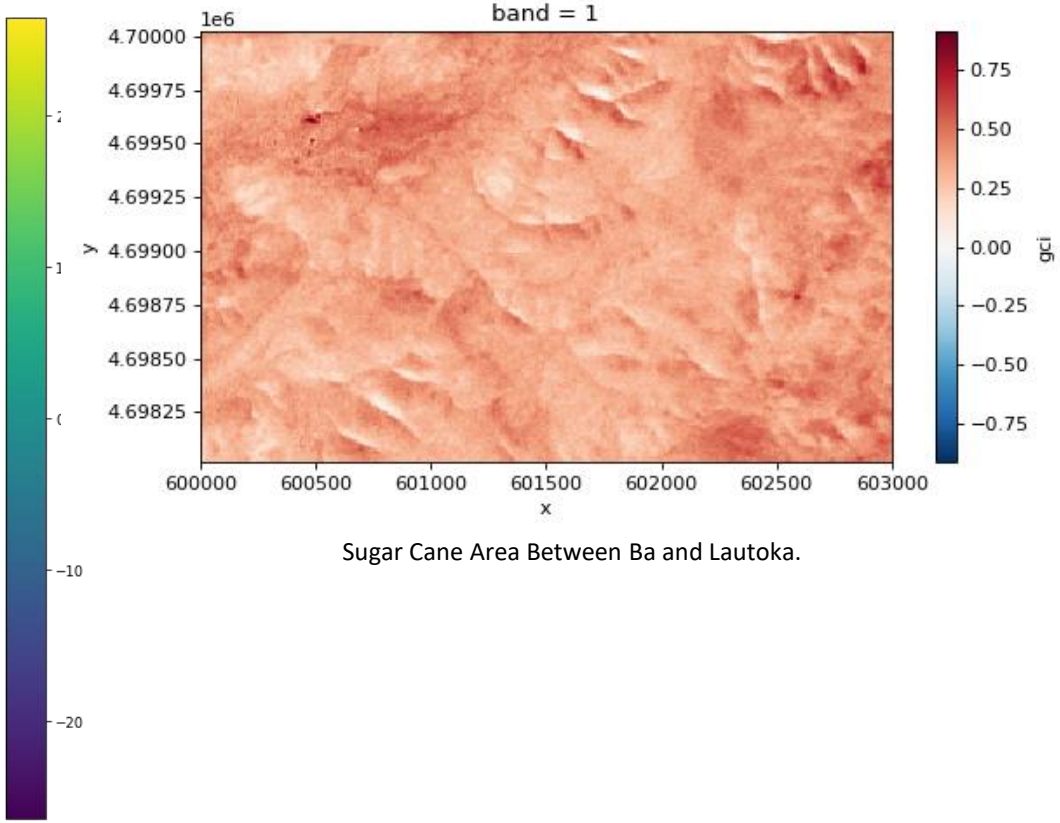


Shows that wetter months and river delta outlets (Ba, Sigatoka) have have higher vegetation moisture.

Phenology: Crop Health

Computes **Green Chlorophyll Index (GCI)**. Used to estimate the content of leaf chorophyll and predict the physiological state of vegetation and plant health.

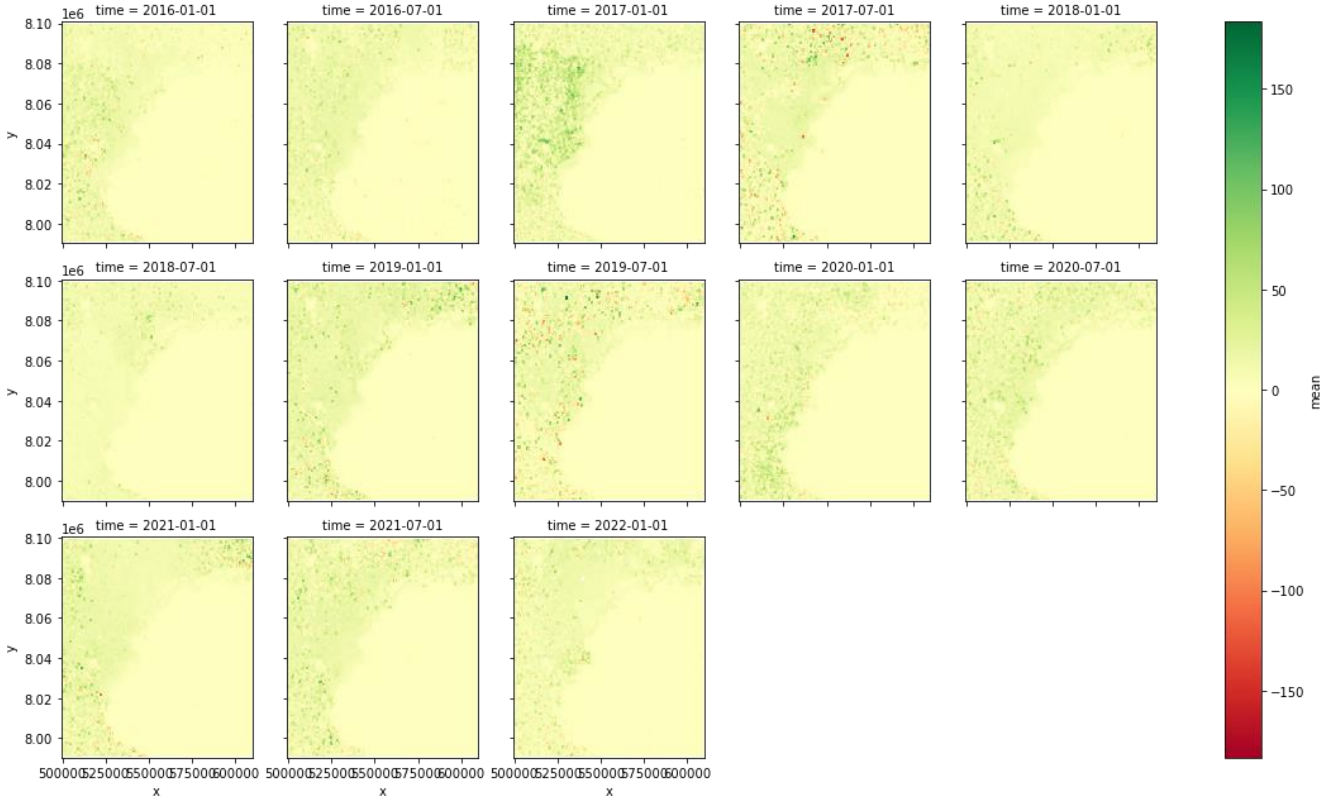


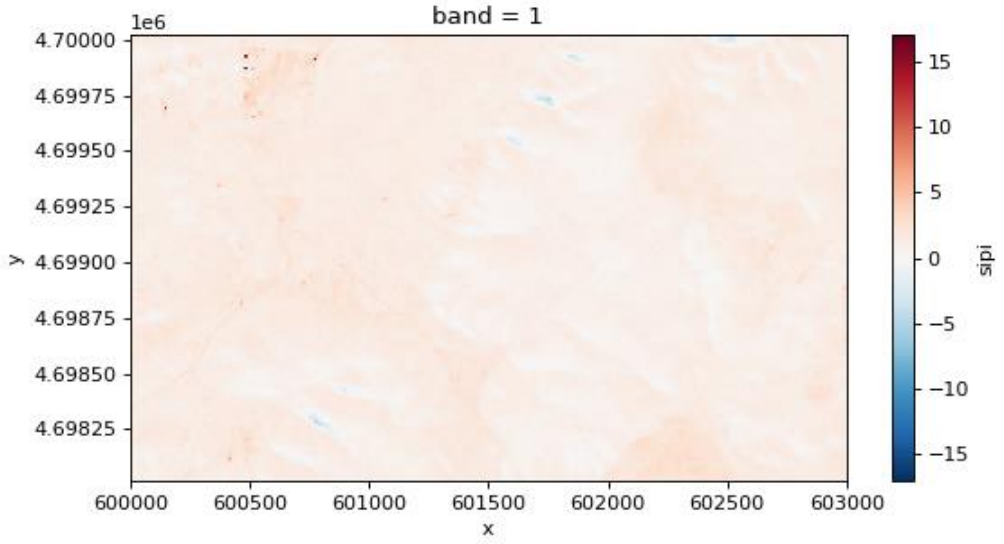


Sugar Cane Area Between Ba and Lautoka.

Phenology: Early Disease Detection

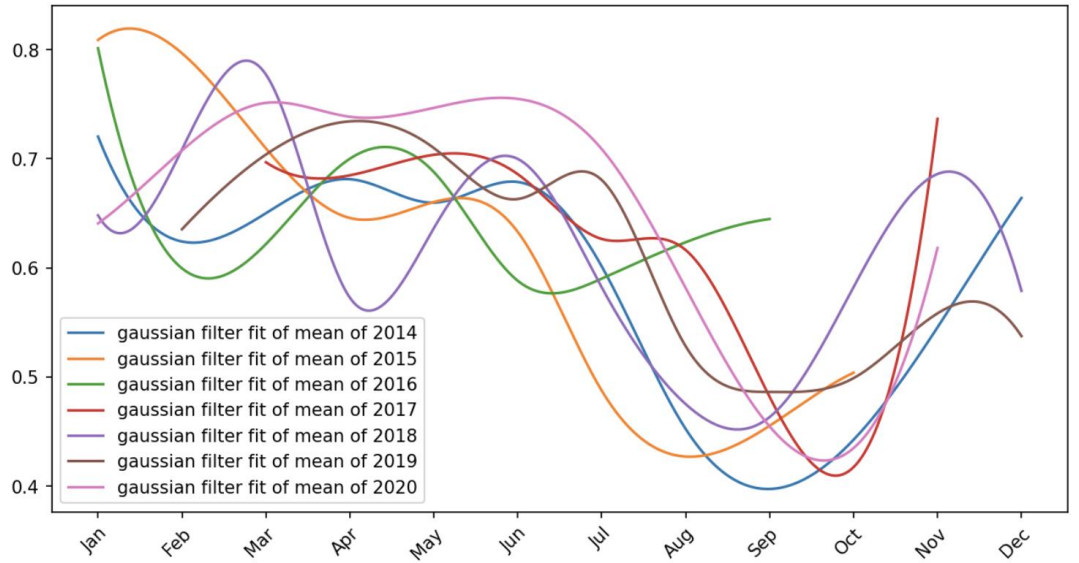
Computes **Structure Insensitive Pigment Index (SIPI)** which helpful in <u>early disease detection in vegetation</u>.

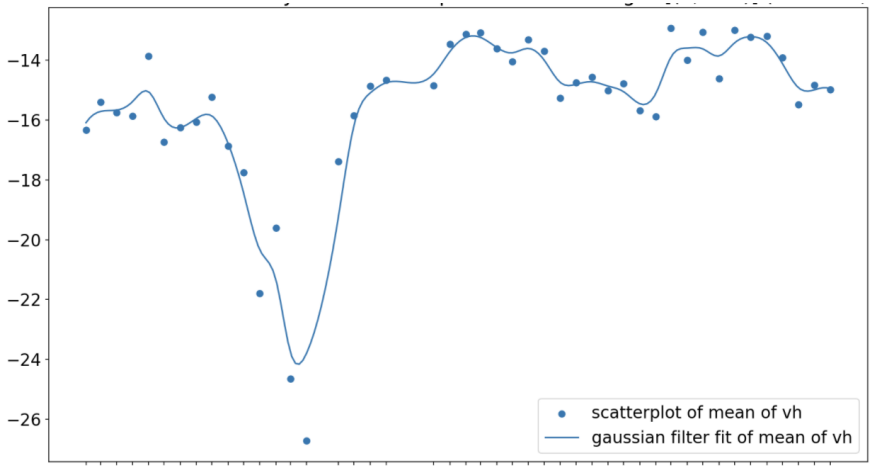




Sugar Cane Area Between Ba and Lautoka.

WiP: Radar Vegetation Index





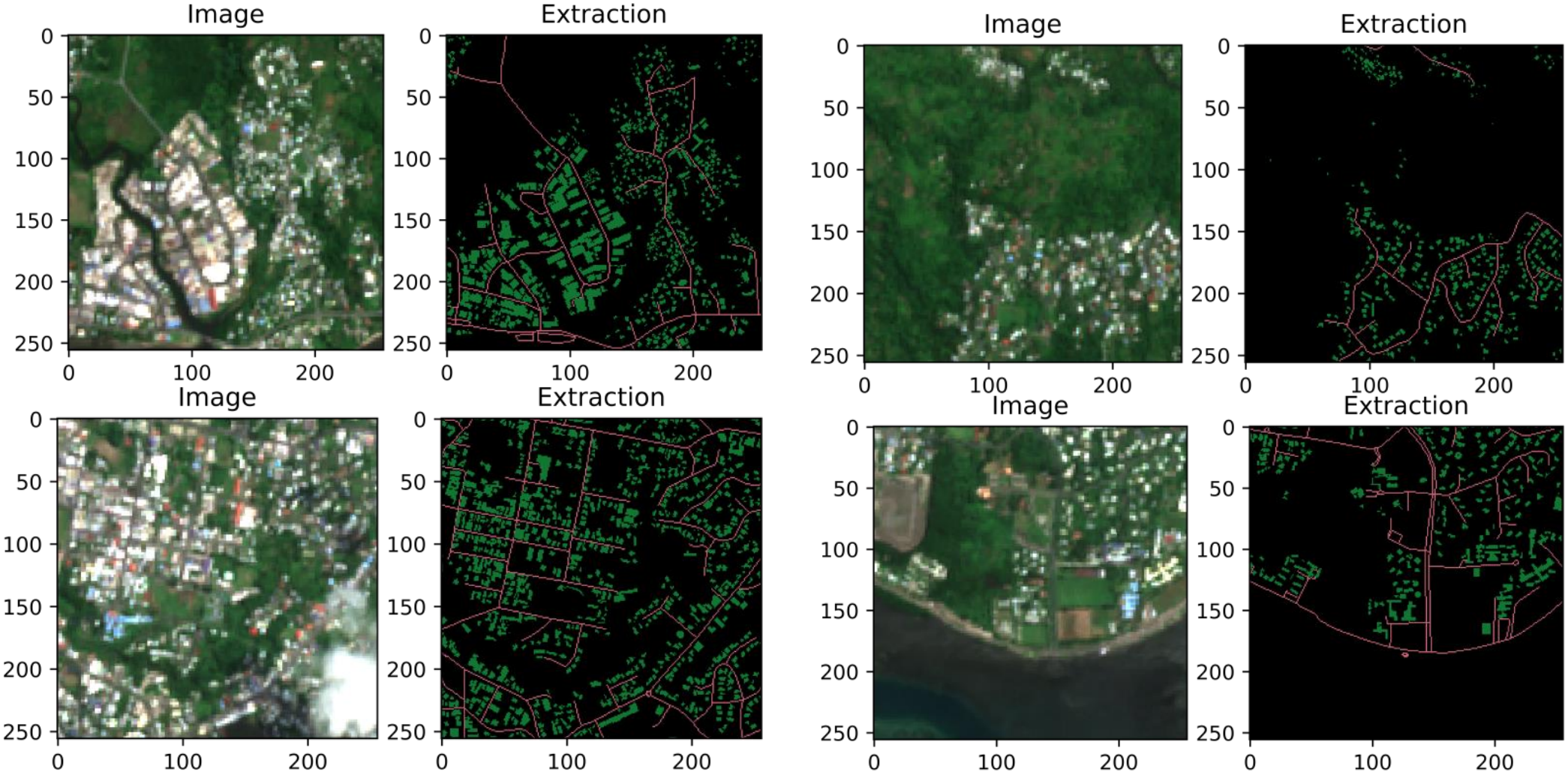
Sentinel-1 (S1) VH Backscatter

Sugar Cane Yield Detection, Ba, Fiji, Dec, 2020

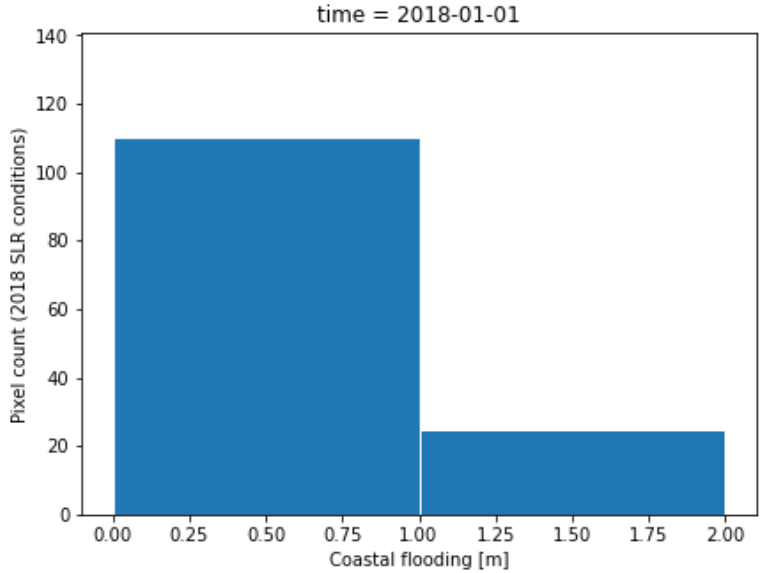
Analysis Conducted By: Dr. Brian Killough (NASA)

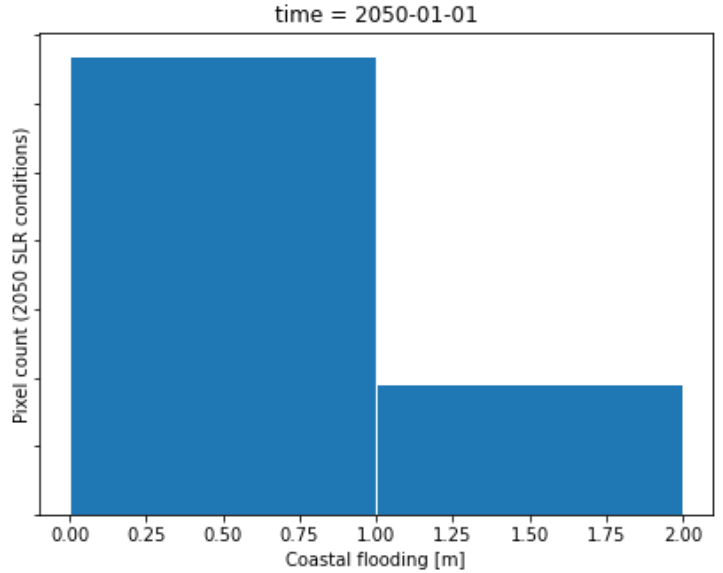
Feature Extraction (Roads, Bldgs)

Using machine-learning model based on data from OSM to identify features such as buildings, roads etc. Critical for disaster planning, response and rapid impact assessment of structures due to an event using post-disaster high-resolution imagery (eg: Tropical Cyclone, Floods, Coastal Inundation)



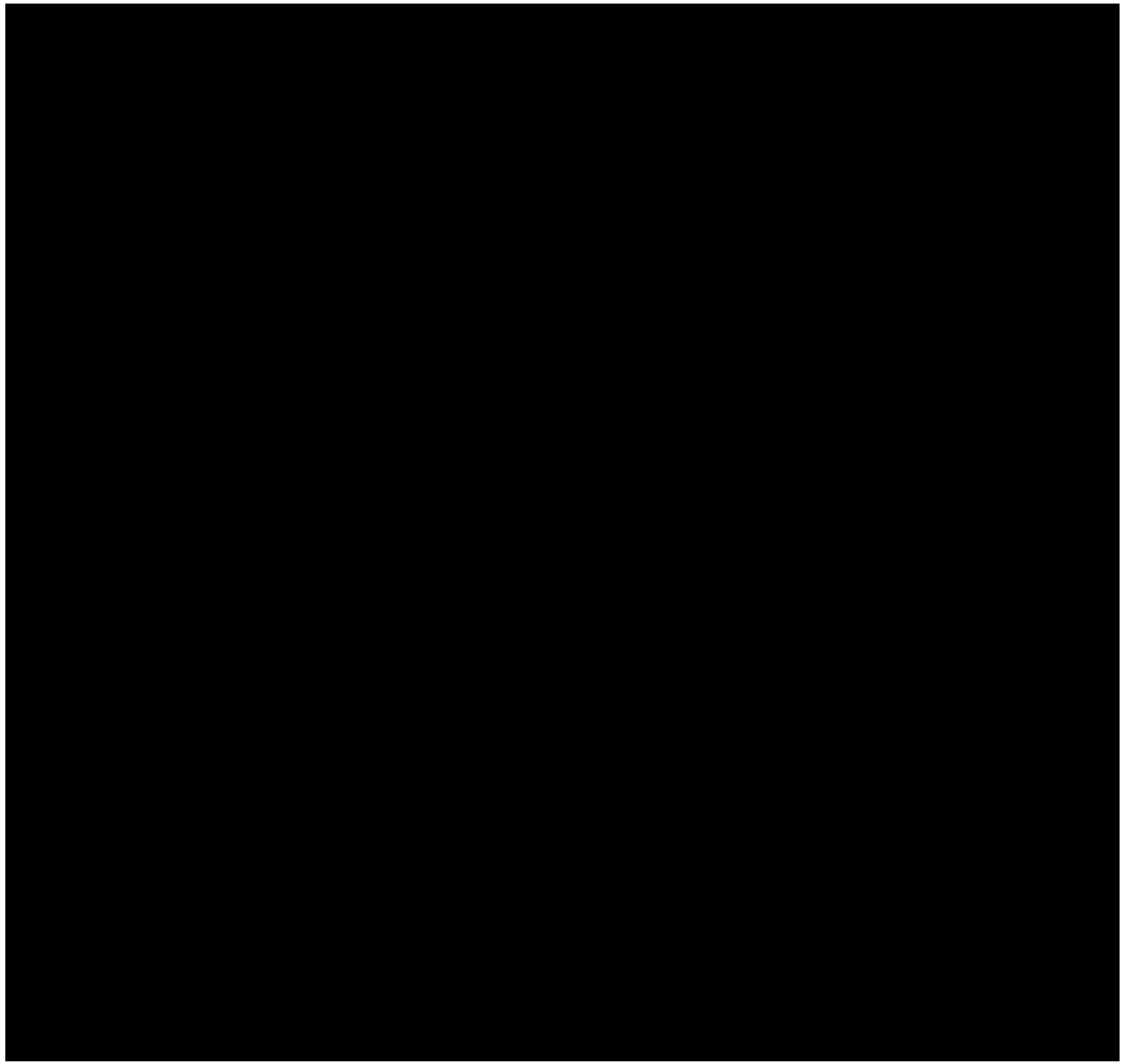
Sea Level Rise Inundation





Inundation model that takes into account water level attenuation and is forced by sea level. Multiple datasets were created using various digital elevation models (DEMs) at multiple resolutions under two different sea level rise (SLR) conditions: current (2018) and 2050.

Spatial Rainfall Analysis



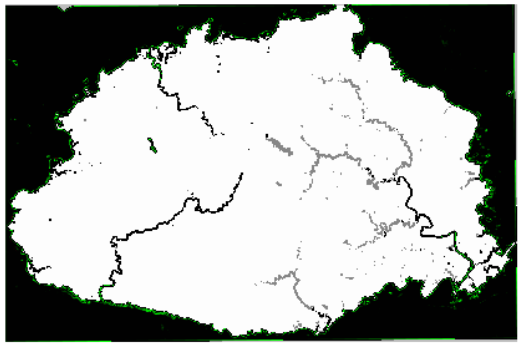
NASA IMERG from GPM Satellite Constellation shows estimated and gauge-calibrated from 2000 onwards at 30 min intervals.

Integration with Fiji Met AWS can potentially further refine resolution of the products.

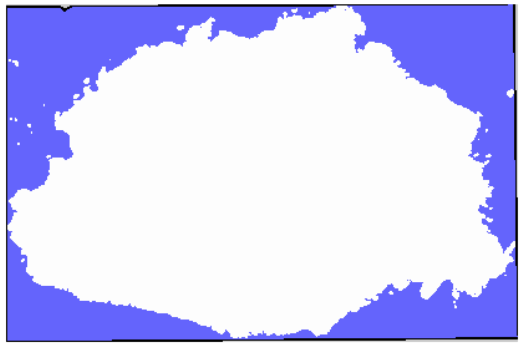
By being able to compare and contrast past and present data, researchers are better informed to make climate and weather models more accurate, better understand normal and extreme rain and drought, and strengthen applications for current and future disasters, disease, resource management, energy production and food security.

Surface Water Change Analysis

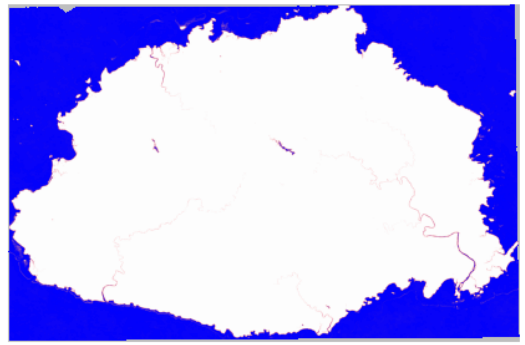
change



extent

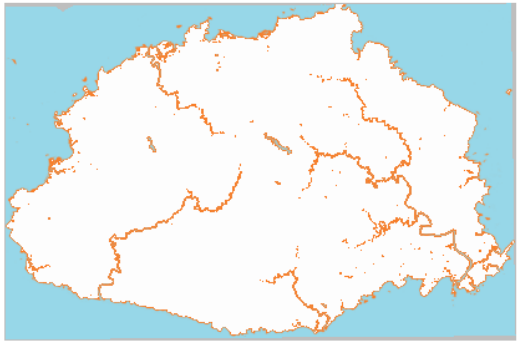


occurrence

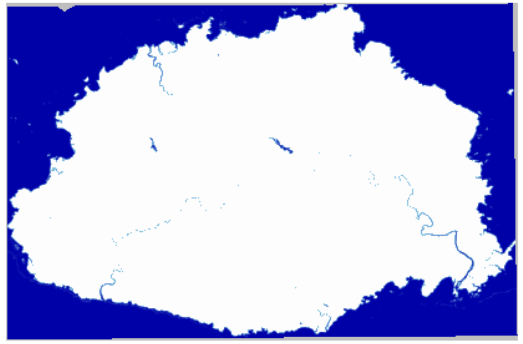


Model show different facets of the spatial and temporal distribution of surface water over the last 32 years (1984 -). Support applications including water resource management, climate modelling, biodiversity conservation and food security.

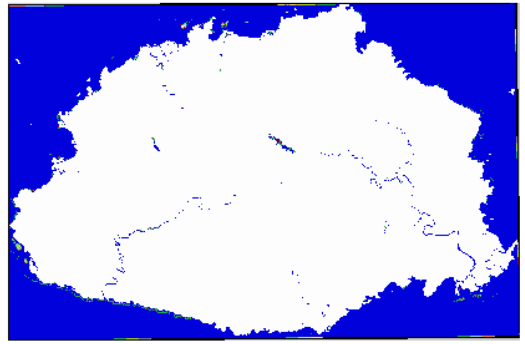
recurrence



seasonality



transitions

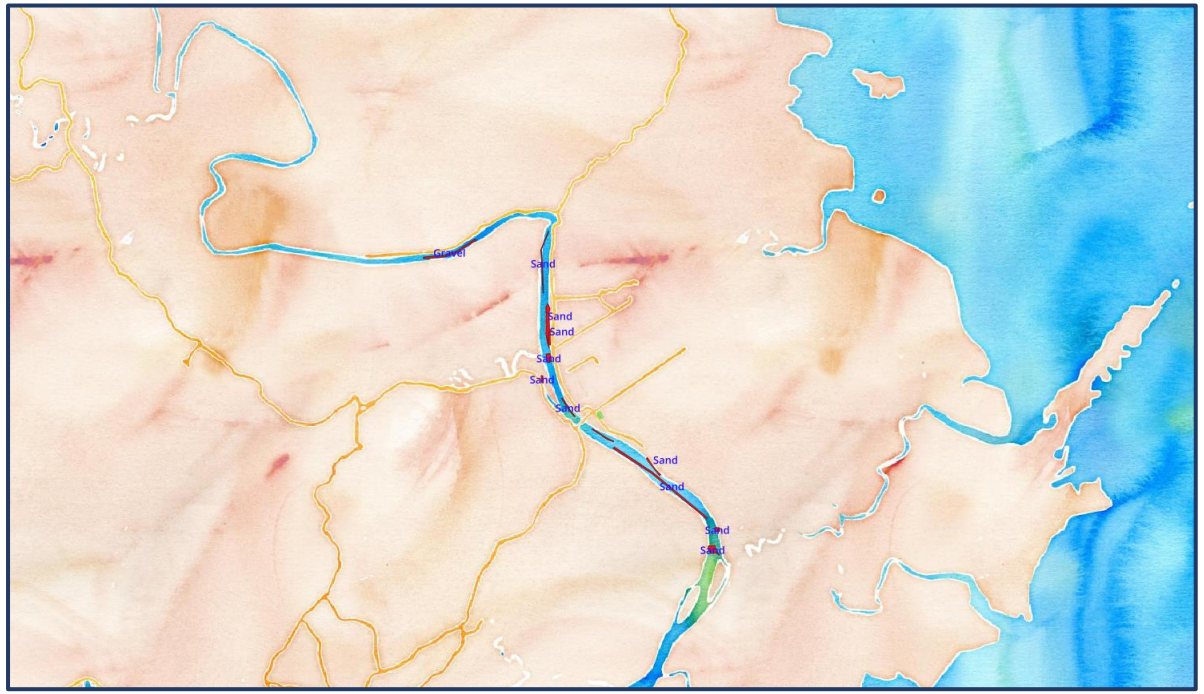


WiP: Unregulated River Extraction

Using River/Waterways Change Detection, NDTI (Turbidity Index), Vegetation Change, and NASA DEM elevation, attempt to implement a nation-wide monitoring system for illegal river extraction of development minerals; such as gravel, sand.

Partnership with UNDP and Fiji Mineral Resources Department (MRD). Further field validation and testing is required to fine-tune the outputs. Workshop in April with MRD to define model thresholds and outputs.

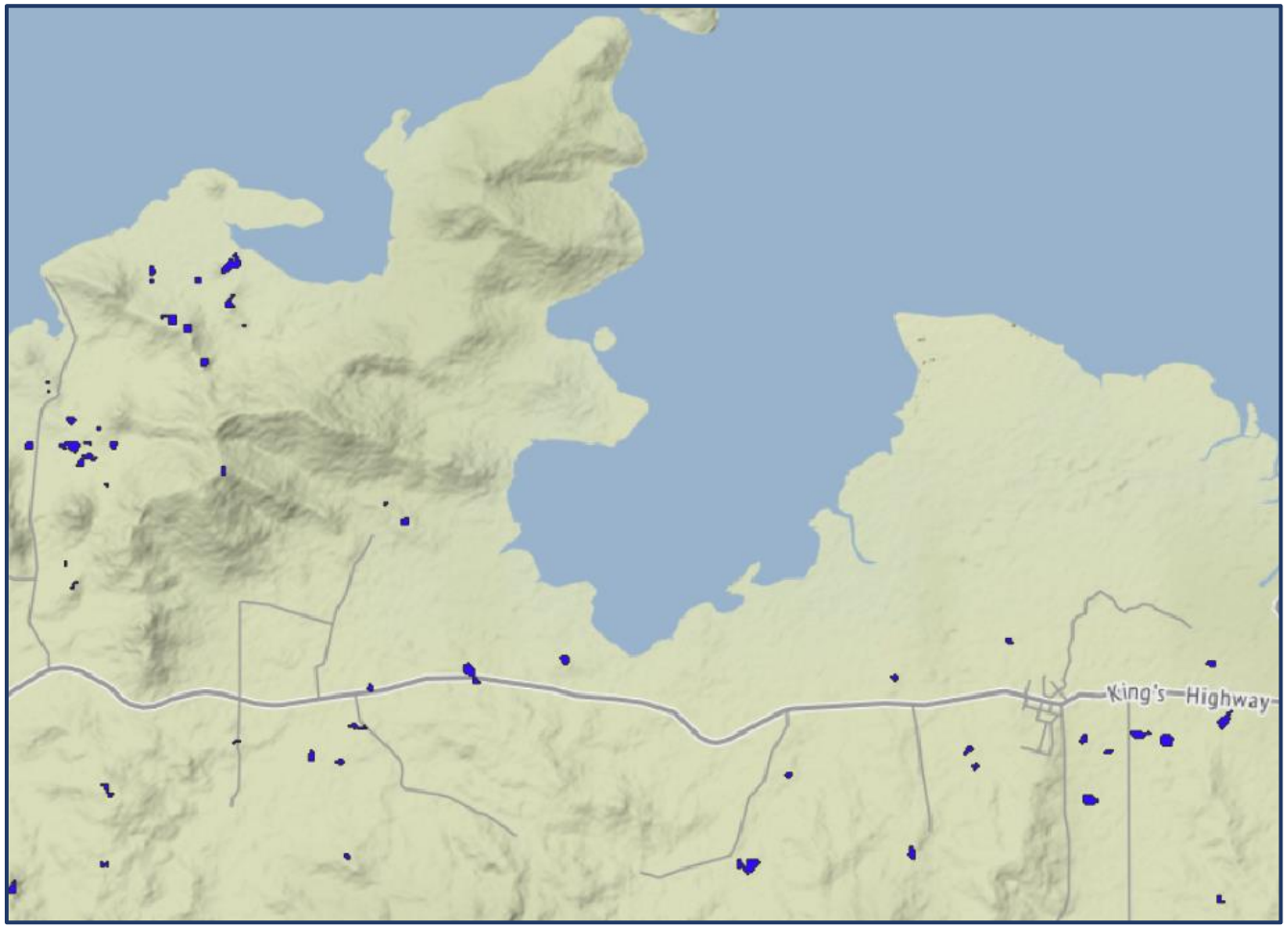
Navua River Extraction



Rewa River Extraction

WiP: S1/SAR Flood Monitoring (1)

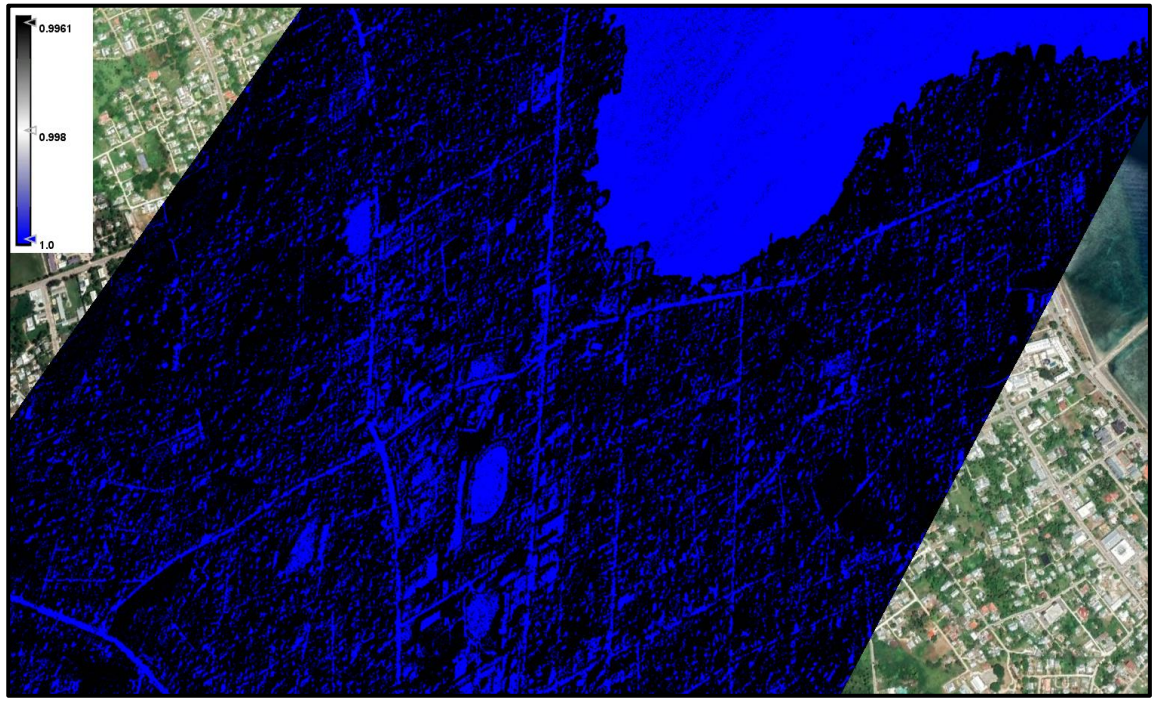
Flood Detection and Monitoring using S1 GRD Radar Data Pipeline



Inundation in Ba-Tavua Corridor
5 - 17 January 2022
(Experimental Product)

WiP: S1/SAR Flood Monitoring (2)

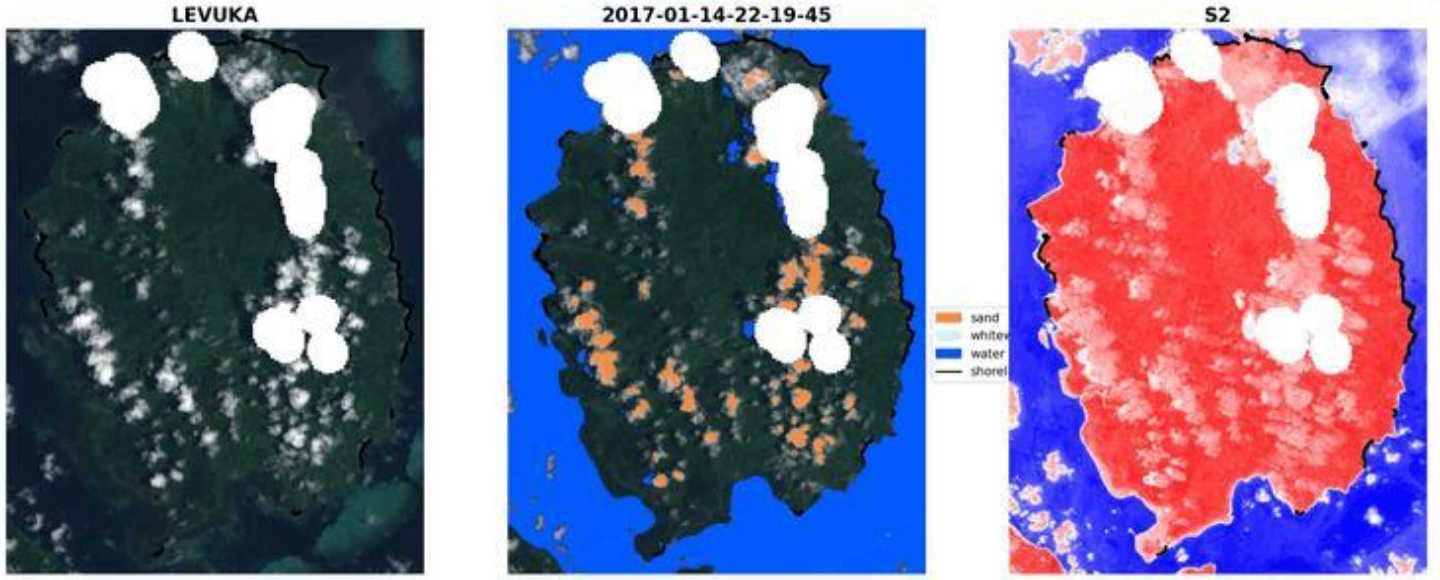
Use Sentinel 1 data pipeline to operationalise automated flood detection and monitoring post-event.

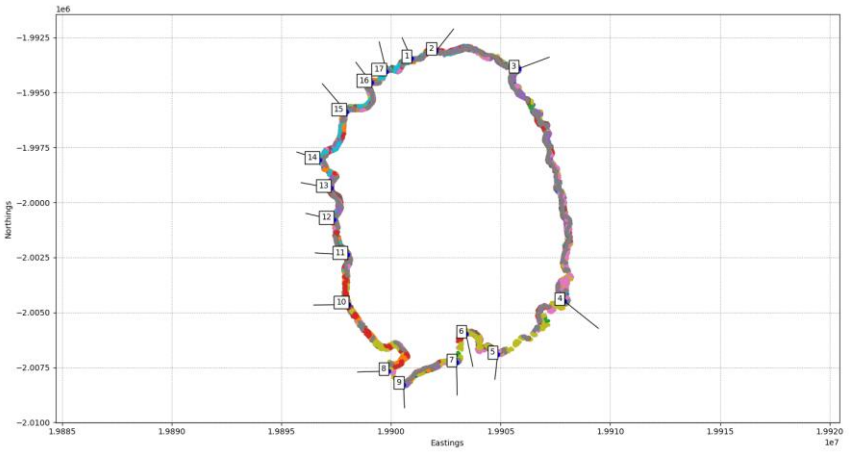


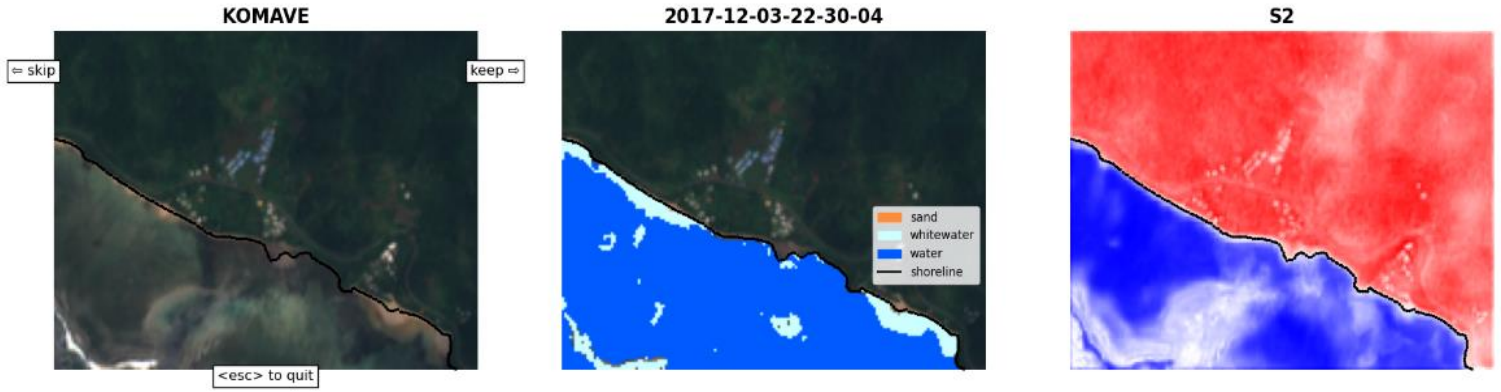
Inundation in Tongatapu post Hunga Tonga–Hunga Ha'apai Event
Jan 2022
(Experimental DEP Product)

Inundation in Navua
December 2016
(Not Produced within DEP)
END GOAL

WiP: Coastline Change w/Tidal Elev.

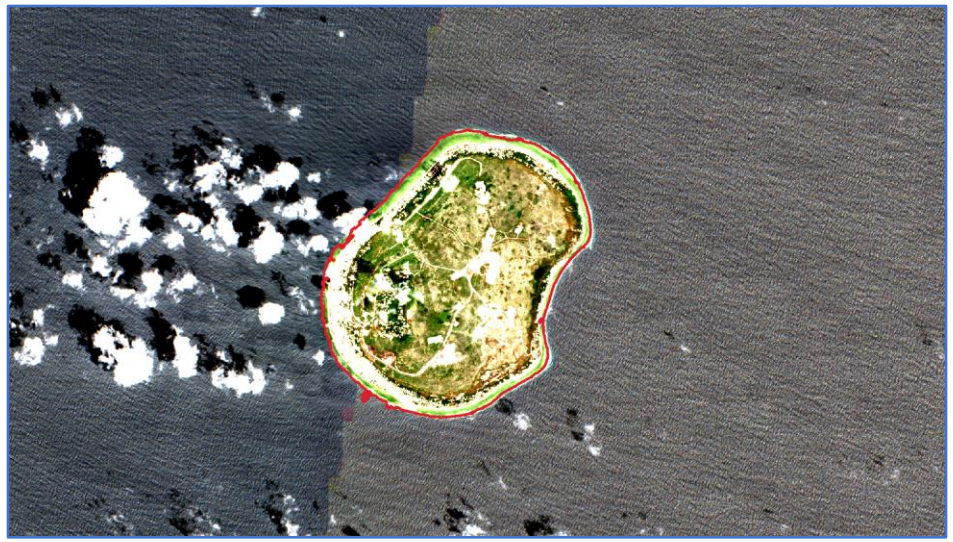


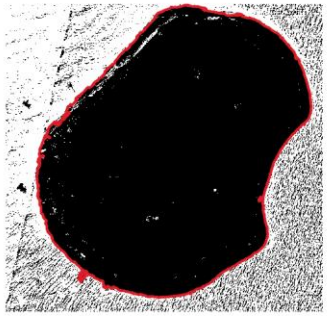




- Experimental Shoreline extraction and analysis at sub-pixel resolution from co-registered S2,L8 imagery.
- **NOT** corrected on Tidal Elevation Models (due to missing capabilities)
- DEP Platform to be enhanced in Phase 2 to support FES2014 (time-series of tide level) to strengthen shoreline change outputs.

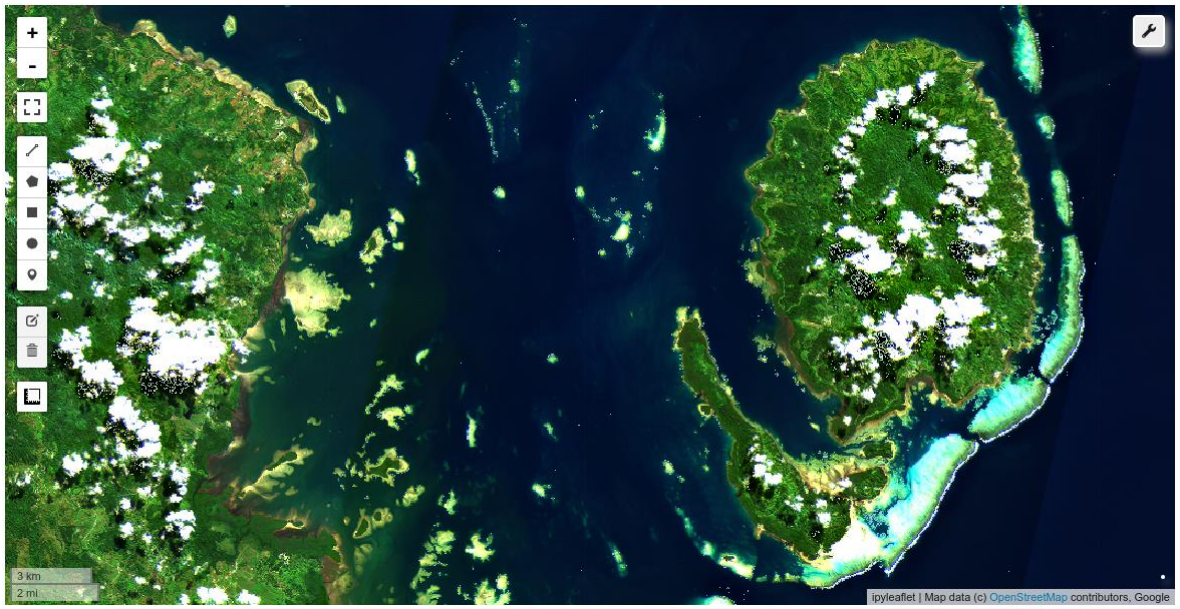
WiP: Coastline Change w/Tidal Elev.

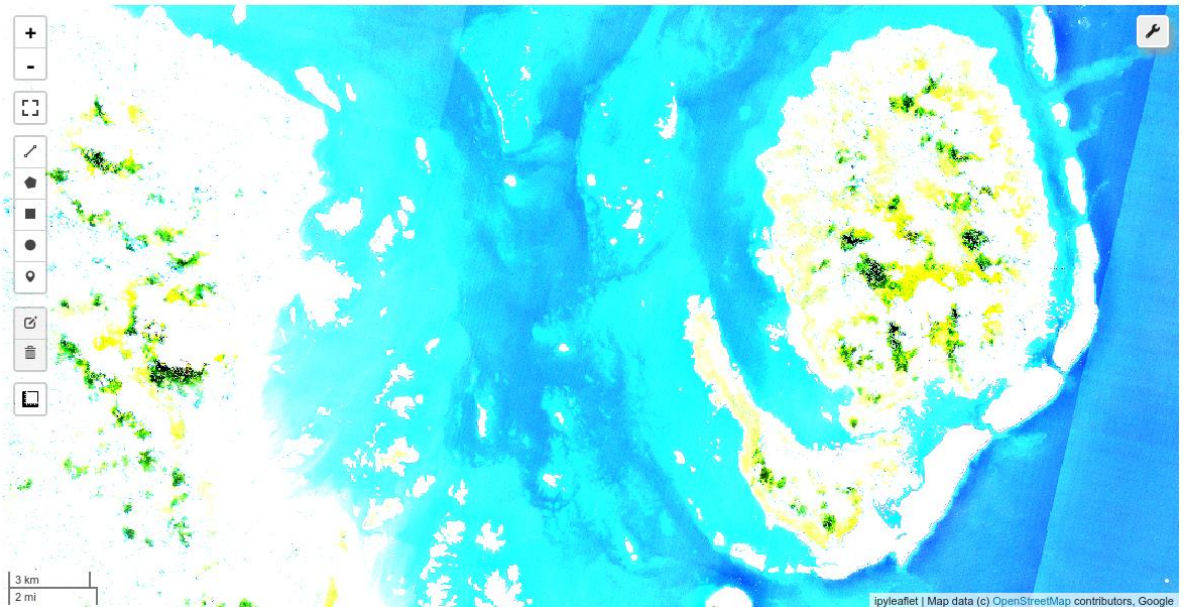




Shoreline Extraction via recently developed **Band Ratio Index**, a recent efficient method, which gives highly accurate results with less processing time and it is able to cover both temporal and spatial aspects of coastline changes. The workflow can be applied on any area using multispectral imagery i.e. Landsat-8, Sentinel-2, etc. A recent remote sensing technique to extract coastline is `Band Ratio`. In this technique the DN values of bands are divided to create a binary raster. NIR, Red and Blue bands were used for creating the binary raster. NIR band is selected as it is able to delineate water-land boundary, Red band is important for vegetation and water content and Blue band has high reflectance in water bodies.

WiP: Near-Shore Bathymetry (S2, SAR)

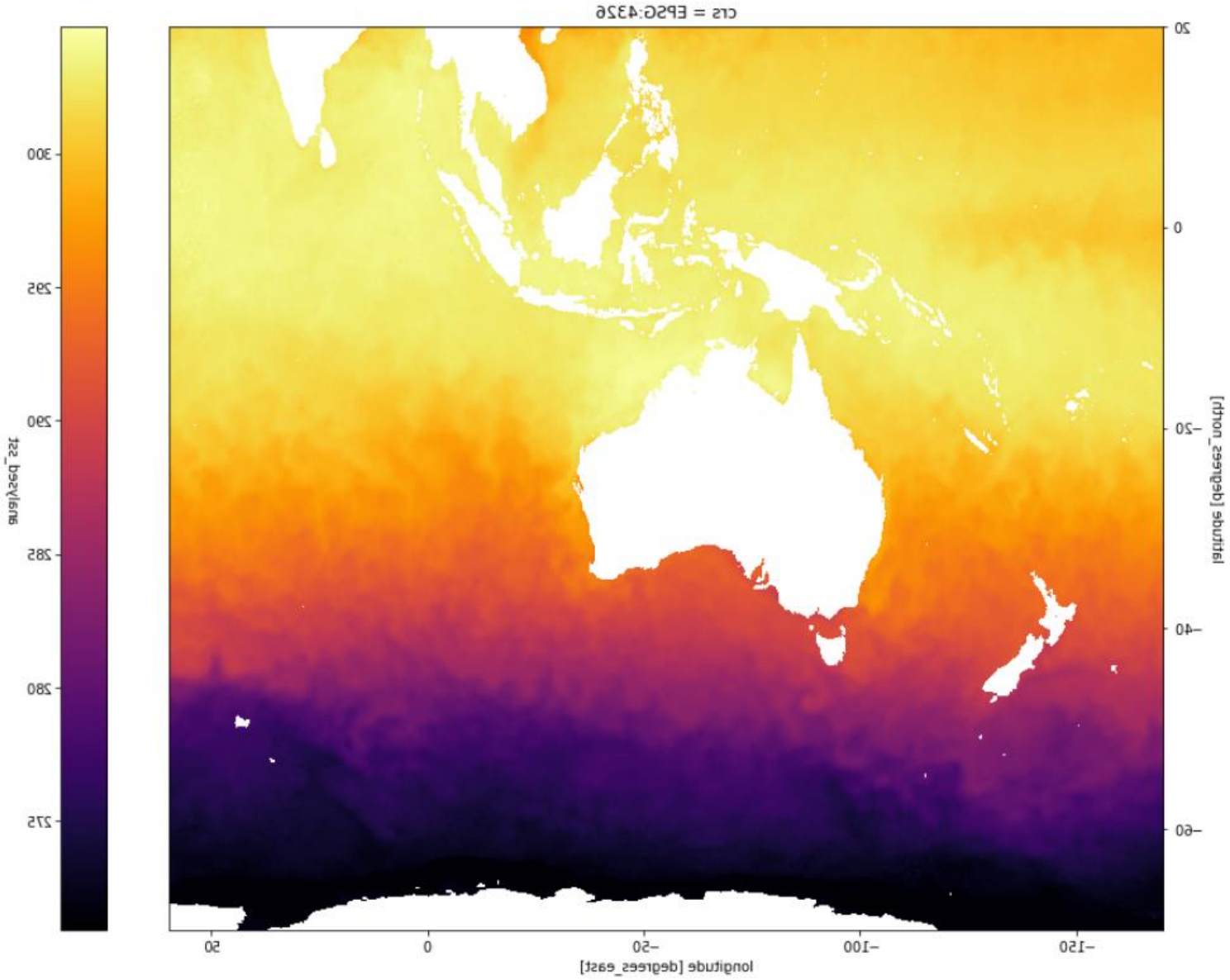


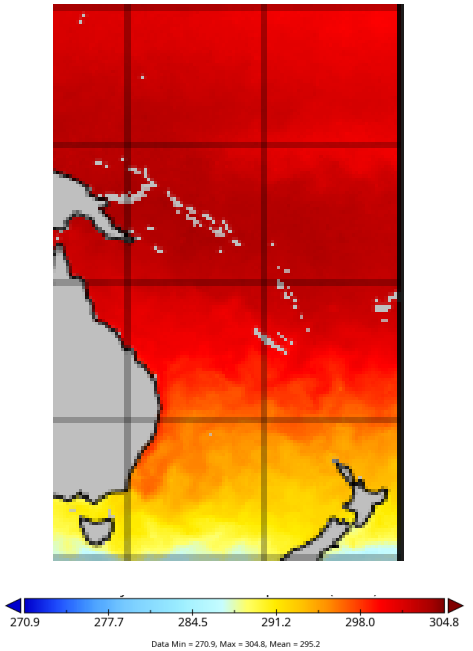


Current methodology uses Sentinel 2 coastal band analysis for shallow water bathymetry up to ~6m depth at 10m/px resolution.

R&D work ongoing on using Sentinel 1 SAR data pipeline to derive bathymetry using peak weak-lengths of long swell waves and shoaling effect. Research results show depths up to –90m.

WiP: Oceans/Meteo Observations





<u>Sentinel 3 @ 300km/2 resolution 1-2 days acquisition interval</u>:

Sea Surface Temperature
Sea-surface Topography,
Sea-Surface Height
Significant Wave Height
Ocean and Land-surface Colour
Sea-water quality, Pollution Monitoring
Marine Weather Forecasting
Climate Modelling and Forecasting

Directory of Future DEP Applications

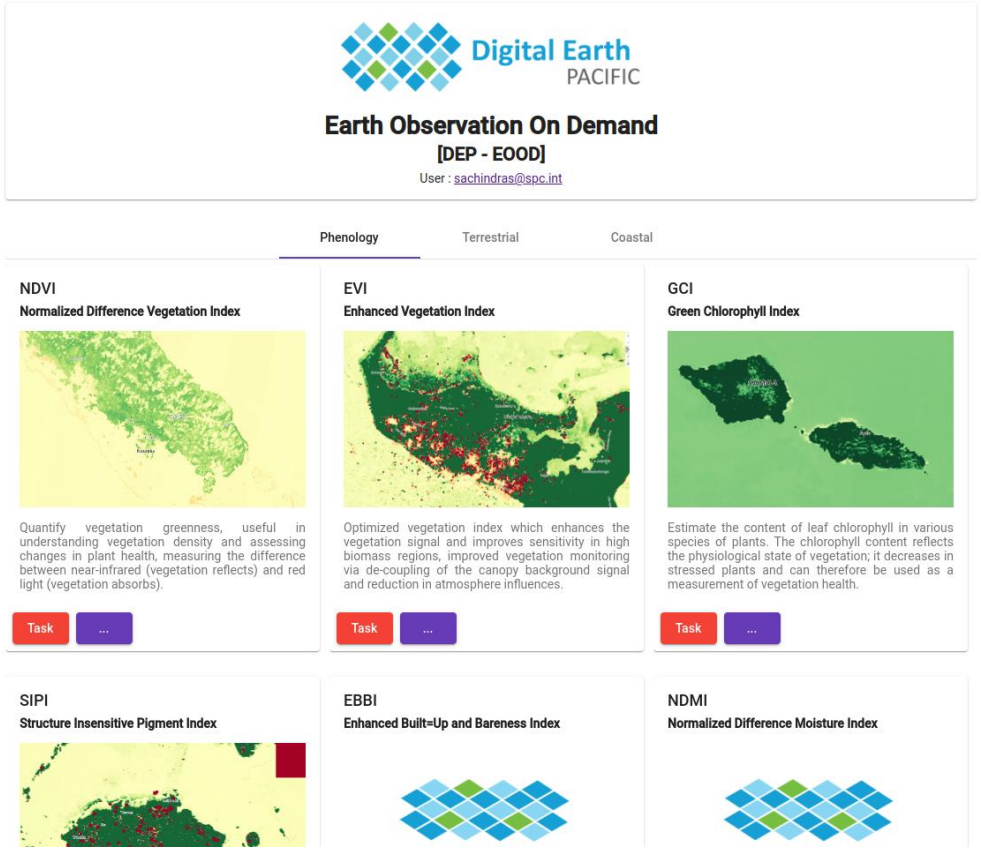
Pacific Community
Communauté du Pacifique

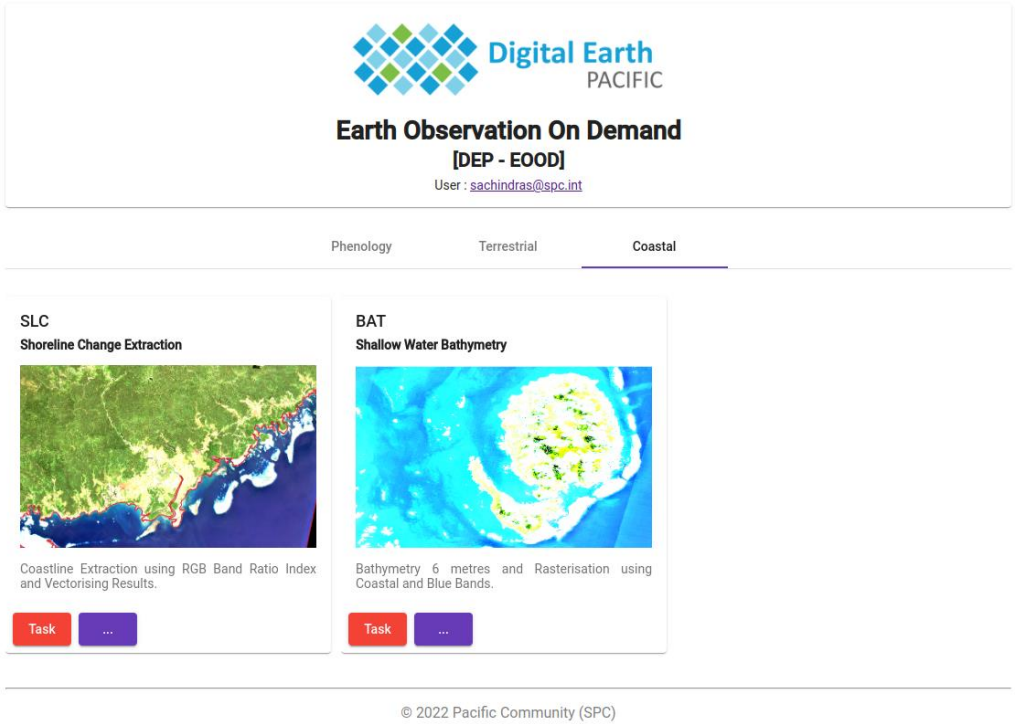
Digital Earth Pacific Spectral Indicies and Related Applications

short_name	long_name	application_domain	formula	bands	reference
AFRI1600	Aerosol Free Vegetation Index (1600 nm)	vegetation	(N - 0.66 * S1) / (N + 0.66 * S1)	['N', 'S1']	https://doi.org/10.1016/S0034-4257(01)00190-0
AFRI2100	Aerosol Free Vegetation Index (2100 nm)	vegetation	(N - 0.5 * S2) / (N + 0.5 * S2)	['N', 'S2']	https://doi.org/10.1016/S0034-4257(01)00190-0
ARI	Anthocyanin Reflectance Index	vegetation	(1 / G) - (1 / RE1)	['G', 'RE1']	https://doi.org/10.1562/0031-8655(2001)074%3C0038:OPANEO%3E2.0.CO;2
ARI2	Anthocyanin Reflectance Index 2	vegetation	N * ((1 / G) - (1 / RE1))	['N', 'G', 'RE1']	https://doi.org/10.1562/0031-8655(2001)074%3C0038:OPANEO%3E2.0.CO;2
ARVI	Atmospherically Resistant Vegetation Index	vegetation	(N - (R - gamma * (R - B))) / (N + (R - gamma * (R - B)))	['N', 'R', 'gamma', 'B']	https://doi.org/10.1109/36.134076
ATSAVI	Adjusted Transformed Soil-Adjusted Vegetation Index	vegetation	sla * (N - sla * R - slb) / (sla * N + R - sla * slb + 0.08 * (1 + sla ** 2.0))	['sla', 'N', 'R', 'slb']	https://doi.org/10.1016/0034-4257(91)90009-U
AVI	Advanced Vegetation Index	vegetation	(N * (1.0 - R) * (N - R)) ** (1/3)	['N', 'R']	http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.465.8749&rep=rep1&type=pdf
AWEInsh	Automated Water Extraction Index	water	4.0 * (G - S1) - 0.25 * N + 2.75 * S2	['G', 'S1', 'N', 'S2']	https://doi.org/10.1016/j.rse.2013.08.029
AWEIsh	Automated Water Extraction Index with Shadows Elimination	water	B + 2.5 * G - 1.5 * (N + S1) - 0.25 * S2	['B', 'G', 'N', 'S1', 'S2']	https://doi.org/10.1016/j.rse.2013.08.029
BAI	Burned Area Index	burn	1.0 / ((0.1 - R) ** 2.0 + (0.06 - N) ** 2.0)	['R', 'N']	https://digital.csic.es/bitstream/10261/6426/1/Martin_Isabel_Serie_Geografica.pdf
BAIM	Burned Area Index adapted to MODIS	burn	1.0/((0.05 - N) ** 2.0) + ((0.2 - S2) ** 2.0)	['N', 'S2']	https://doi.org/10.1016/j.foreco.2006.08.248
BAIS2	Burned Area Index for Sentinel 2	burn	(1.0 - ((RE2 * RE3 * N2) / R) ** 0.5) * (((S2 - N2)/(S2 + N2) ** 0.5) + 1.0)	['RE2', 'RE3', 'N2', 'R', 'S2']	https://doi.org/10.3390/ecrs-2-05177
BCC	Blue Chromatic Coordinate	vegetation	B / (R + G + B)	['B', 'R', 'G']	https://doi.org/10.1016/0034-4257(87)90088-5
BI	Bare Soil Index	urban	((S1 + R) - (N + B))/((S1 + R) + (N + B))	['S1', 'R', 'N', 'B']	http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.465.8749&rep=rep1&type=pdf
BLFEI	Built-Up Land Features Extraction Index	urban	((((G+R+S2)/3.0)-S1)/((((G+R+S2)/3.0)+S1)	['G', 'R', 'S2', 'S1']	https://doi.org/10.1080/10106049.2018.1497094
BNDVI	Blue Normalized Difference Vegetation Index	vegetation	(N - B)/(N + B)	['N', 'B']	https://doi.org/10.1016/S1672-6308(07)60027-4
BWDRVI	Blue Wide Dynamic Range Vegetation Index	vegetation	(alpha * N - B) / (alpha * N + B)	['alpha', 'N', 'B']	https://doi.org/10.2135/cropsci2007.01.0031
BaI	Bareness Index	urban	R + S1 - N	['R', 'S1', 'N']	https://doi.org/10.1109/IGARSS.2005.1525743
CIG	Chlorophyll Index Green	vegetation	(N / G) - 1.0	['N', 'G']	https://doi.org/10.1078/0176-1617-00887
CIRE	Chlorophyll Index Red Edge	vegetation	(N / RE1) - 1	['N', 'RE1']	https://doi.org/10.1078/0176-1617-00887
CSI	Char Soil Index	burn	N/S2	['N', 'S2']	https://doi.org/10.1016/j.rse.2005.04.014
CSIT	Char Soil Index Thermal	burn	N / (S2 * T1 / 10000.0)	['N', 'S2', 'T1']	https://doi.org/10.1080/01431160600954704
CVI	Chlorophyll Vegetation Index	vegetation	(N * R) / (G ** 2.0)	['N', 'R', 'G']	https://doi.org/10.1007/s11119-010-9204-3
DBI	Dry Built-Up Index	urban	((B - T1)/(B + T1)) - ((N - R)/(N + R))	['B', 'T1', 'N', 'R']	https://doi.org/10.3390/land7030081
DBSI	Dry Bareness Index	urban	((S1 - G)/(S1 + G)) - ((N - R)/(N + R))	['S1', 'G', 'N', 'R']	https://doi.org/10.3390/land7030081
DPDD	Dual-Pol Diagonal Distance	radar	(VV + VH)/2.0 ** 0.5	['VV', 'VH']	https://doi.org/10.1016/j.rse.2018.09.003
DVI	Difference Vegetation Index	vegetation	N - R	['N', 'R']	https://doi.org/10.1016/0034-4257(94)00114-3
DVIplus	Difference Vegetation Index Plus	vegetation	((lambdaN - lambdaR)/(lambdaN - lambdaG)) * G + (1.0 - ((lambdaN - lambdaR)/(lambdaN - lambdaG))) * N - R	['lambdaN', 'lambdaR', 'lambdaG', 'G', 'N', 'R']	https://doi.org/10.1016/j.rse.2019.03.028
DpRVIHH	Dual-Polarized Radar Vegetation Index HH	radar	(4.0 * HV)/(HH + HV)	['HV', 'HH']	https://www.tandfonline.com/doi/abs/10.5589/m12-043

Desktop research and literature review of 200+ Spectral Indicies and other algorithms across S2, L8 and SAR Data Sources, that can be turned into DEP-generated change detection products. (Ongoing work)

DEP On Demand (EOOD)





Zero-code environment for decision-makers to submit EO analytical batch tasks across Vegetation Phenology, Land Cover and Coastal domains over a **user-defined** area-of-interest, timeframe, and resolution. *In prototype testing stage.*

Merci

https://www.spc.int/DigitalEarthPacific

Workshop on Sunday:
Hands On Using Digital Earth Pacific Computing Hub via JupyterHub/Python environment. Applications include: *cloudless mosaicing, landcover change detection, shoreline extraction* etc.

Data Products and Pipelines Portal

https://explore.digitalearthpacific.org