WORLD OCEAN CIRCULATION

PRODUCT USER MANUAL
LAGRANGIAN DRIFT OF *SARGASSUM* AND OIL SPILLS
(THEME 3)

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1 Introduction

1.1 Purpose of the document

The present document is the Product User Manual dedicated to the content and format description of the added value products from Theme 3: Drift of *Sargassum* and oil spills.

This is the primary document that users should read before handling the products. It provides an overview of processing algorithms, technical product content and format and main validation results.

1.2 Document structure

In addition to this introduction, this document includes the following chapters:

- Chapter 2 describes the *Sargassum* drift algorithm and products generated
- Chapter 3 describes the Oil spill drift algorithm and products generated

1.3 Applicable & Reference documents

- Miron, P., Olascoaga, M. J., Beron-Vera, F. J., Putman, N. F., Triñanes, J., Lumpkin, R., & Goni, G. J. (2020). Clustering of Marine-Debris-and Sargassum-Like Drifters Explained by Inertial Particle Dynamics. *Geophysical Research Letters*, *47*(19), e2020GL089874. https://doi.org/10.1029/2020GL089874.

- Algorithm Theoretical Basis Document for Lagrangian drift of sargassum and oil spills https://docs.google.com/document/d/1H5mSHvurVQvzrE1zfoSNMa6_CEK7qJ1eHKRoK8J0HRM/edit#

- Pålsson, J., Hildebrand, L., & Lindén, O. (2017). COMPARING SWEDISH OIL SPILL PREPAREDNESS TO REGIONAL COUNTRIES USING THE RETOS™ EVALUATION TOOL. In *International Oil Spill Conference Proceedings* (Vol. 2017, No. 1, pp. 21-36). International Oil Spill Conference. https://doi.org/10.7901/2169-3358-2017.1.21

- Requirements Baseline document;
  https://docs.google.com/document/d/1oLwJIbWRUBhWvTJte_qQcWLVBq8BvGbA/edit

- Kelly, S., Popova, E., Aksenov, Y., Marsh, R., & Yool, A. (2018). Lagrangian modeling of Arctic Ocean circulation pathways: Impact of advection on spread of pollutants. Journal of Geophysical Research: Oceans, 123, 2882- 2902. https://doi.org/10.1002/2017JC013460

- Bobra AM and MF Fingas (1986) The Behaviour and Fate of Arctic Oil Spills. Water Sci Technol, 18, 13–23. doi: https://doi.org/10.2166/wst.1986.0012

- Gower, J., & King, S. (2019). Seaweed, seaweed everywhere. Science, 365(6448), 27. https://doi.org/10.1126/science.aay0989

- Qiao, F., Wang, G., Yin, L., Zeng, K., Zhang, Y., Zhang, M., ... & Chen, G. (2019). Modelling oil trajectories and potentially contaminated areas from the Sanchi oil spill. Science of the Total Environment, 685, 856-866. https://doi.org/10.1016/j.scitotenv.2019.06.255
- National Oceanography Center (NOC), Southampton, UK, 2018b National Oceanography Center (NOC), Southampton, UK. Coral reefs may be at risk from Sanchi oil tanker contamination http://noc.ac.uk/news/coral-reefs-may-be-risk-sanchi-oil-tanker-contamination
- Pan, Q., Yu, H., Daling, P. S., Zhang, Y., Reed, M., Wang, Z., ... & Zou, Y. (2020). Fate and behavior of Sanchi oil spill transported by the Kuroshio during January–February 2018. Marine Pollution Bulletin, 152, 110917. https://doi.org/10.1016/j.marpolbul.2020.110917
- Chen, L., Yang, J., & Wu, L. (2019). Modeling the dispersion of dissolved natural gas condensates from the Sanchi incident. Journal of Geophysical Research: Oceans, 124(11), 8439-8454. https://doi.org/10.1029/2019JC015637
- Wang, M., Hu, C., Barnes, B. B., Mitchum, G., Lapointe, B., & Montoya, J. P. (2019). The great Atlantic Sargassum belt. Science, 365(6448), 83–87. https://doi.org/10.1126/science.aaw7912

1.4 Terminology

ATBD	Algorithm Theoretical Basis Document
HFO	Heavy Fuel Oil
RB	Requirements Baseline

2 Lagrangian drift of Sargassum

2.1 Overview

While normally confined to the Sargasso Sea in the centre of the subtropical Atlantic gyre, the floating *Sargassum* seaweed has in recent years invaded the Caribbean Sea, leading to large-scale littering of beaches and wreaked havoc to the regional tourism sector that is faced with beaches full of stinking *Sargassum* (Gower and King, 2019). This Caribbean invasion of *Sargassum* has been traced back to increased growth in the tropical Atlantic, but it is unclear which pathways exactly the *Sargassum takes* (Wang *et al.,* 2019). Better predictability of new waves of *Sargassum* invading the Caribbean thus require more advanced tools to track the floating seaweed, ideally in remote sensed flow fields.

The Langrangian drift of *Sargassum* added value product represents the trajectories of *Sargassum* in the Tropical Atlantic. The product focuses on the years 2018 and 2019, years when a high abundance of *Sargassum* has been observed in this region. For instance, in June 2018 a monthly mean *Sargassum* of more than 20 million tons was observed (Wang *et al.*, 2019).

The products generated are the following:

- Hourly outputs of horizontal 2D *Sargassum* drift in the tropical Atlantic at 15m during 180 days initialized at the drifters' release location in the field study by Miron *et al* 2020:
    - 20180312070000-WOC-L4-CURlag_15m-TATL_SARGASSUM_DRIFT_1H_DRIFTERS_d1-v2.0-fv1.0.nc
    - 20180315080000-WOC-L4-CURlag_15m-TATL_SARGASSUM_DRIFT_1H_DRIFTERS_d2-v2.0-fv1.0.nc
    - 20180322010000-WOC-L4-CURlag_15m-TATL_SARGASSUM_DRIFT_1H_DRIFTERS_d3-v2.0-fv1.0.nc
    - 20180329060000-WOC-L4-CURlag_15m-TATL_SARGASSUM_DRIFT_1H_DRIFTERS_d4-v2.0-fv1.0.nc
- Hourly outputs of horizontal 2D *Sargassum* drift in the tropical Atlantic at 15m during 1 day during May 2019:
    - 20190513134155-WOC-L4-CURlag_15m-TATL_SARGASSUM_DRIFT_1H_SAT-v2.0-fv1.0.nc

The preliminary results obtained are generated using the version 2 velocity product which only include velocity fields at 15m. In some cases this velocity is enough to represent the test cases, but in future versions the surface dynamics (wind effects and Stokes drift) will be added, together with specific *Sargassum* drift behaviour to improve the simulated trajectories. For further details on the validation see the ATBD (https://docs.google.com/document/d/1H5mSHvurVQvzrE1zfoSNMa6_CEK7qJ1eHKRoK8J0HRM/edit#).

2.2 Algorithm

2.2.1 Retrieval methodology

The Lagrangian drift of Sargassum is simulated using the OceanParcels framework (www.OceanParcels.org). OceanParcels is an open-source software, which has been developed by Utrecht University (Netherlands) to simulate the dispersion of plastic material in the ocean. The frontend of the OceanParcels framework is written in python, and has a back-end written in C for speed and efficiency. The Parcels code (**P**robably **A** **R**eally **C**omputationally **E**fficient **L**agrangian **S**imulator) consists of a set of Python classes and methods to create customisable particle tracking simulations using velocities from for example outputs from Ocean Circulation models. Version 2.3 of Parcels is used here (Delandmeter & van Sebille, 2019; https://github.com/OceanParcels/parcels/releases).

The processing followed in the generation of the data is shown in figure 1.

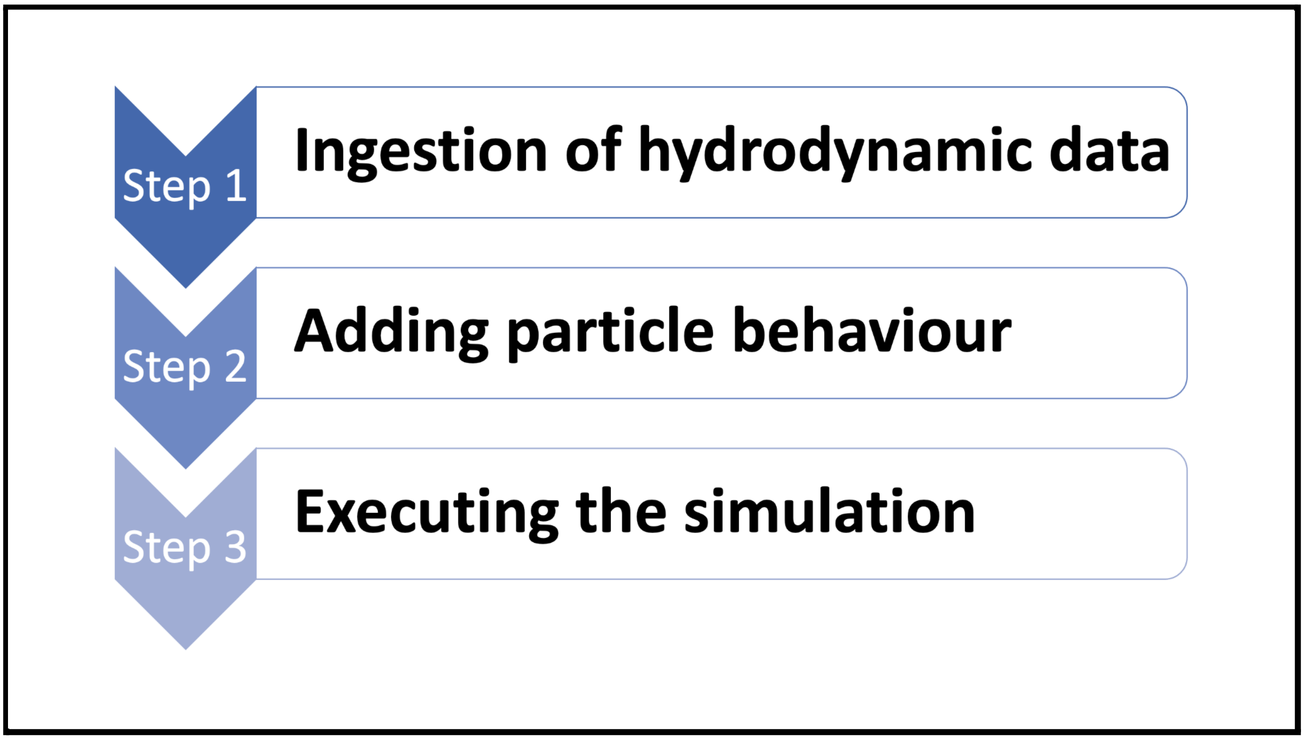


Figure 1. Flowchart describing the processing followed to generate the Surface Lagrangian drift simulations of *Sargassum*.

The ocean parcels software uses the velocity fields to advect particles and simulate their trajectories. The velocity field inputs can be in different formats, and here we use netCDFs. The velocity fields used are a combination of satellite and drifter data. The data is available from 2010 to 2020, has a spatial resolution of 1/4˚, an hourly temporal resolution and is available at 15m depth. The spatial resolution of 1/4˚ is due to the fact that the satellite geostrophic velocities from CMEMS and the ERA5 wind data have this spatial resolution, and it also provides a light product which can have a greater spatial coverage. Here we focus on velocity data from the Tropical Atlantic region in the years 2018 and 2019, for case 1 and 2, respectively. For more information on the input data see:
https://docs.google.com/document/d/1qVwZfxmd9iQF2YL1ZYGjmgVqo0oSnqUu_HCWmQ94fDk/edit

The particles' (*Sargassum* in this case) behaviour is represented here as a Lagragian drift by horizontally advecting them (in 2D) using the ingested velocity fields. The velocity fields used here include geostrophic currents, inertial oscillations and Ekman transport. In this second version (v2.0) preliminary simulation of the product, we assume the *Sargassum* follows the total velocity of the new currents product at 15m. This allows us to first understand the particles' trajectories with this new velocity field, and in next versions the surface dynamics (wind effects and Stokes drifts) will be added as well as the *Sargassum* particles' behaviour.

The main kernel is the horizontal advection of particles. The new velocity product includes two components: a geostrophic and an ageostrophic (Ekman transport and inertial oscillations) one. This to velocity fieldsets are included in the advection kernel. Particles which reach the ocean boundaries of the domain are deleted using the DeleteParticle function. For the *Sargassum* drifters simulation, an additional kernel is created : the AgeParticle kernel. As the particles are released at different times, it allows to keep track of the age of the particles released on different dates and times, and to simulate their trajectories for the same amount of days.

Trajectories are integrated using a two-dimensional fourth-order Runge-Kutta scheme with an integration time step of 10 minutes. The 2D position of each particle is stored every hour. A jupyter-notebook example of the code is shown in fig. 2.

```
[45]: def DeleteParticle(particle, fieldset, time):
          particle.delete()

      def AgeParticle(particle, fieldset, time):
          if particle.state == ErrorCode.Evaluate:
              particle.age += math.fabs(particle.dt)
          if particle.age > fieldset.maxage:
              particle.delete()

      class DrifterParticle(JITParticle):
          age = Variable('age')
          launch_id = Variable('launch_id', to_write='once')
```

2.4 ParticleSet:

```
[46]: pset_v2 = ParticleSet(fieldset=fieldset_total, pclass=DrifterParticle, lon=list(launch_lons),
                          lat=list(launch_lats), time=list(launch_times_s), launch_id=list(launch_ids))  #, depth=depp, launch_id=list(launch_ids))
```

3. Executing the simulation:

3.1. Defining parameters

```
[47]: fieldset_total.maxage = timedelta(days=180.).total_seconds()
      runtime = (max(list(launch_times_s))-min(list(launch_times_s))) + fieldset_total.maxage

      outdir =  "/storage/shared/oceanparcels/output_data/data_LauraGN/WOC/Sargassum/v02/"
      pfname = 'd1_v02_ATL_Miron_2018.nc'

      output_file = pset_v2.ParticleFile(name=outdir + pfname, outputdt=timedelta(hours=1))
```

3.2 Running

```
•[48]: pset_v2.execute(pset_v2.Kernel(AdvectionRK4)+AgeParticle, runtime=runtime, dt=timedelta(minutes=10),
                    recovery={ErrorCode.ErrorOutOfBounds: DeleteParticle}, output_file=output_file) #runtime=+AgeParticle

       start_time = launch_times[0]
       time_unit_out= "seconds since " + str(pset_v2.time_origin)
       end_time = (num2date(output_file.lasttime_written, time_unit_out)).isoformat()

       add_WOC_nc_attbts(output_file, start_time, end_time, ds.lon.data.min(), ds.lon.data.max(), ds.lat.data.min(), ds.lat.data.max()
               , input_filename="WOC-L4-CUReul-KUR-1H: runconv15m_enatl2_d2*.nc"
               , ntitle="Tropical Atlantic 2D horizontal drift of Sargassum for ESA WOC project"
               , summary="This dataset contains the positions of virtual particles released following the Miron et al (2020) field study at 15m representing the trajectories of Sargassum in the Tropical Atlantic."
               , inid = "TATL_SARGASSUM_DRIFT_1H_DRIFTERS"
               , ndepth = "15")

       output_file.export()  # exports the trajectory data to a netcdf file
```

Figure 2. Example of kernel set-up for the execution of the drifters *Sargassum* simulation at location d1.

Once the hydrodynamic input data and particle behaviour kernels are reading, the simulations can be run and saved as netCDFs. To do so, a set of parameters need to be decided:

- **Timestep (dt)** : 10 minutes
- **Output timestep (dt) :** Hourly
- **Simulation length:**
    - Case 1 (drifters scenario) : 180 days
    - Case 2 (satellite scenario) : 1 day
- **Initial positions and release dates :**
    - Case 1 (drifters scenario) : Release locations and times following Miron *et al*. (2018). Figure 3 shows the release locations of the particles at the 4 sites of the Miron *et al*. (2020) field study. At each point 3 drifters are released of the type sargassum-like, one undrogued and one drogued drifter.

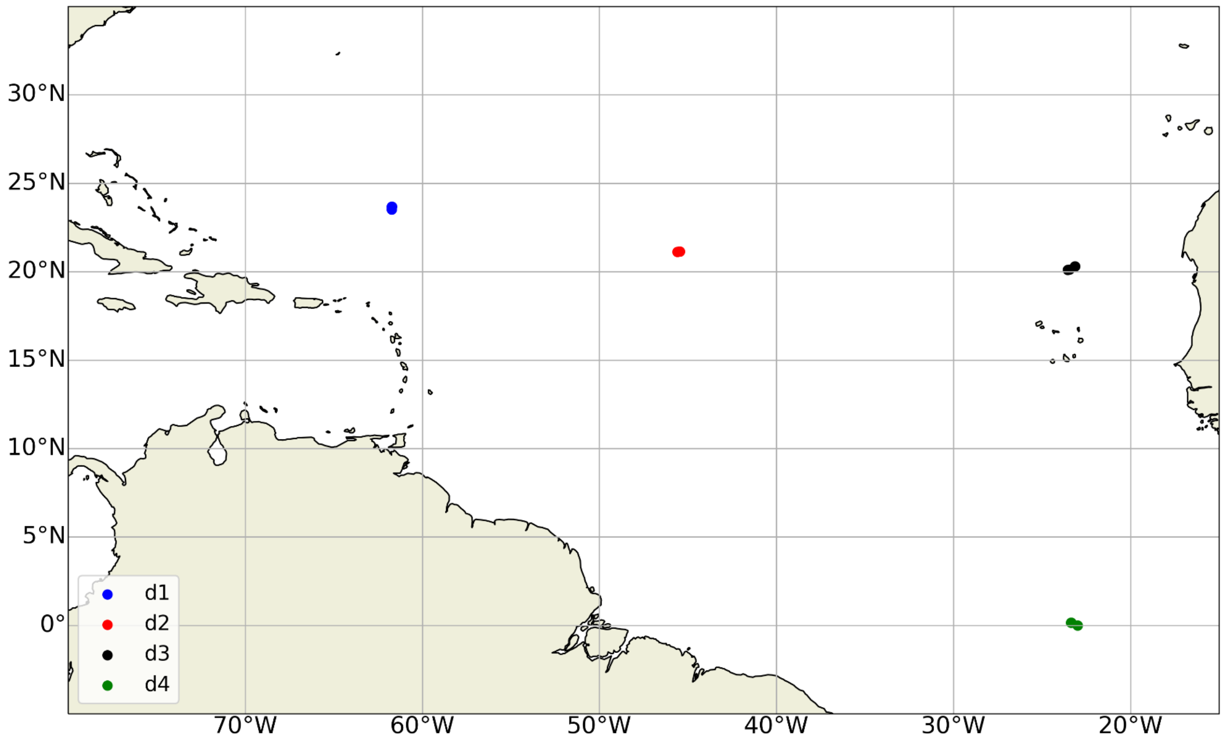


Figure 3. Release locations (d1, d2, d3 and d4) of the particles following Miron et al. (2020).

- Case 2 (satellite scenario): Release locations where *Sargassum* meshes have been identified on satellite images (information provided by MeteoFrance). Particles are released on a regular grid (mesh) with a spacing of 0.02° around the satellite image location (fig. 4).

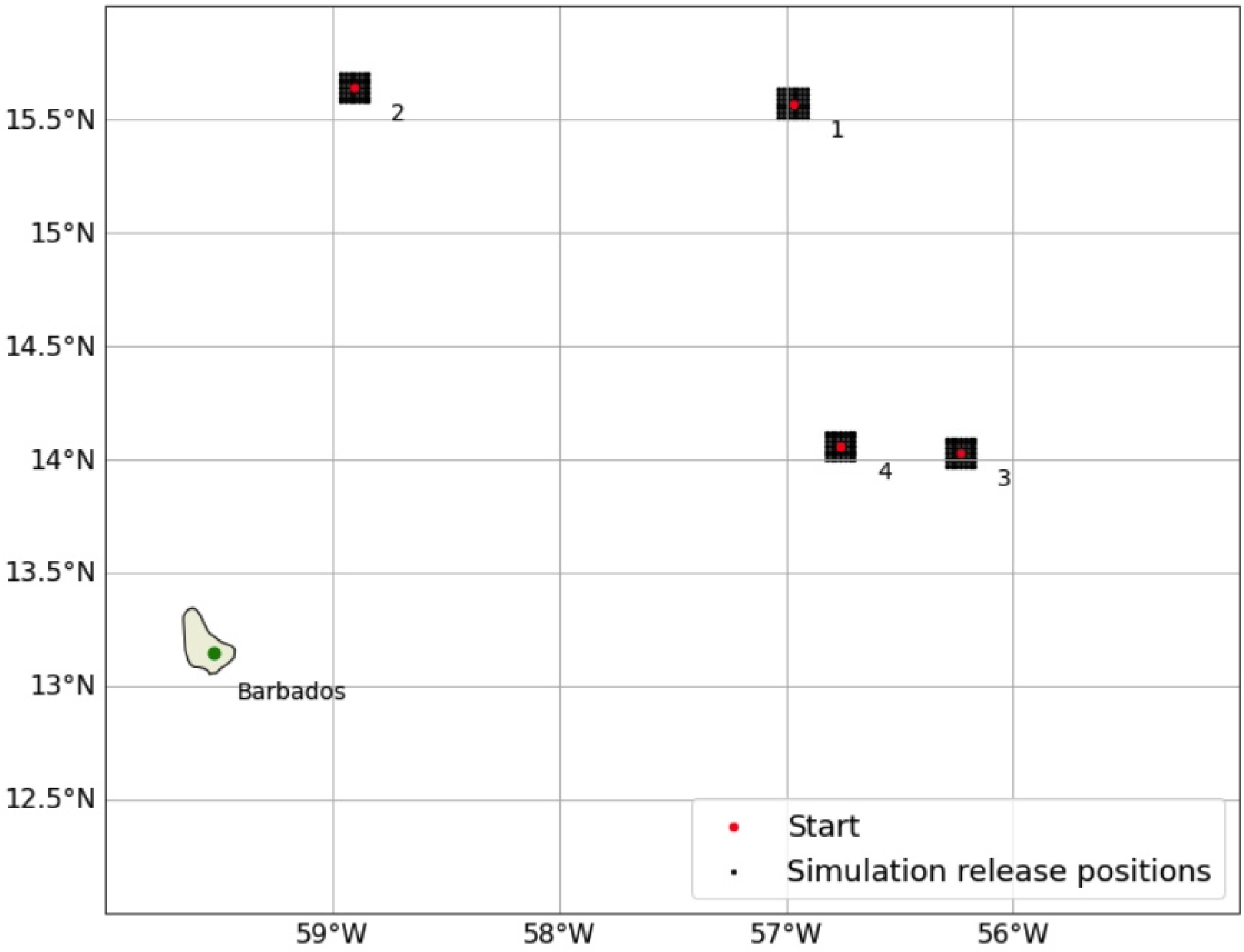


Figure 4. Release locations of the virtual *Sargassum* particles (black) around the 4 locations where *Sargassum* mats have been identified on the satellite image (red).

2.2.2. Limitations

In this preliminary simulation of version 2.0 of the product, data is generated using the version 2 velocity product which only includes velocity fields at 15m. In some cases this velocity is enough to represent the test cases, but in future versions the surface dynamics (wind effects and Stokes drift) will be added, together with specific *Sargassum* drift behaviour to improve the simulated trajectories. This will be explored in next versions, though limitations will still exist due to the difficulty to couple the ocean currents data with the biogeochemistry. For example, the presence (or not) of nutrients affecting the growth of *Sargassum*.

The ageostrophic component of the currents is now available as separate components, so it is no longer a limitation in order to test in the next version the effect of different components (e.g. inertial oscillations and Stokes drift). On the other hand, the new currents product is only available at one depth (15m), so the vertical displacement of the particles, and its effect on the horizontal displacement cannot be so easily implemented.

2.2.3. Differences with previous version

- Parcels version used in v1.0 was 2.2.2 and now version 2.3. The updates of the new parcels version can be found here : https://github.com/OceanParcels/parcels/releases/tag/v2.3.0
- A new case study is included, the satellite scenario during May 2019.

- For the drifters scenarios, two more release locations (d3 and d4) are included thanks to the extension of the Tropical Atlantic region farther east and south.

2.3 Product Description

2.3.1 Spatial information

The trajectories of Sargassum are obtained in the Tropical Atlantic. The spatial resolution is representative of the spatial resolution of the hydrodynamic data used (1/4°).

2.3.2 Temporal information

This data is generated for the years 2018 and 2019 for scenario 1 and 2, respectively. The position of the virtual particles representing *Sargassum* drift are generated every hour. The drifter *Sargassum* simulation is run for 180 days , the average length of the drifter trajectories in Miron *et al* (2020) (scenario 1). The *Sargassum* simulation for the satellite images (scenario 2) is run for 24 hours, a period for which two consecutive Sargassum images are available.

2.3.3 Product content

Table 1. Product information for *Sargassum* simulations.

Dataset name	Parameter usual name	Variable name	units
• 20180312070000-WOC-L4-CURlag_15m-TATL_SARGASSUM_DRIFT_1H_DRIFTERS_d1-v2.0-fv1.0.nc • 20180315080000-WOC-L4-CURlag_15m-TATL_SARGASSUM_DRIFT_1H_DRIFTERS_d2-v2.0-fv1.0.nc • 20180322010000-WOC-L4-CURlag_15m-TATL_SARGASSUM_DRIFT_1H_DRIFTERS_d3-v2.0-fv1.0.nc • 20180329060000-WOC-L4-CURlag_15m-TATL_SARGASSUM_DRIFT_1H_DRIFTERS_d4-v2.0-fv1.0.nc • 20190513134155-WOC-L4-CURlag_15m-TATL_SARGASSUM_DRIFT_1H_SAT-v2.0-fv1.0.nc	time	time	seconds since 1970-01-01
	trajectory: Unique identifier for each particle	trajectory	-
	latitude	lat	degrees_north
	longitude	lon	degrees_east
	depth	z	metres (positive down)

2.3.4 File name convention

The filename convention followed is:

<Indicative Date><Indicative Time>-WOC-<Processing Level>-<Parameter>-<Product String>-v< Product Version>-fv<File Version>.<File Type>

Where:

- Indicative Date: date of the release of the first particle in YYYYmmdd format
- Indicative Time: time of the release of the first particle in HHMMSS format
- Processing Level: level here is L4
- Parameter: CURlag_15m here (Currents Lagrangian drift at 15m depth)
- Product String: gives information on the simulation (depth, region, particle type, temporal resolution and particle release type), e.g. TATL_SARGASSUM_DRIFT_1H_DRIFTERS_d1
- Product Version: For example, v2.0 here
- File Version: For example, fv.10 here
- File Type: 'nc' as, as explained in section 2.3.5 below, files are saved in netCDF format so 'nc'

2.3.5 File format

The files are saved in NetCDF4 format. As they are 2D lagrangian simulations, the dimensions are trajectory and observation. Trajectory is the unique identifier for each virtual particle and observation indicates the number of observations (positions of the particles) obtained, and is equivalent to time.

2.3.6 Metadata

Table 2. Metadata description of *Sargassum* simulation output files.

Element name	**Description**
standard_name_vocabulary	The source of the standard name table
title	A short description of the dataset.
license	Licensing policy (open)
tracking_id	A UUID allowing this file to be uniquely referenced back against other information in a database, providing complete provenance on request
keywords	A comma separated list of key words and phrases.
id	The file name
history	An audit trail for modifications to the original data.
naming authority	Identifies a namespace provider

creation_date	Time of file creation date_created
creator_name creator_email	The data creator's name, URL, and email. The "institution" attribute will be used if creator_url the "creator_name" attribute does not exist.
project	The scientific project that produced the data.
time_coverage_start	Describe the temporal coverage of the data as a time range.
time_coverage_end time_coverage_duration time_coverage_resolution	
processing_level	A textual description of the processing level of the data.
geospatial_lat_min geospatial_lat_max geospatial_lat_resolution geospatial_lon_min geospatial_lon_max geospatial_lon_resolution	Describe a simple latitude, longitude, and vertical bounding box.

3 Lagrangian drift of Oil Spills

3.1 Overview

The North Atlantic region is associated with pollution monitoring applications, where the added value products focus on combating oil spills. Oil spills in the northern part of the North Atlantic (Arctic) are very difficult to manage, hence rapid-response tools are particularly important here (Bobra and Fingas 1986, Kelly *et al* 2018). With the receding of Arctic sea ice, shipping of the Arctic is only expected to grow, and hence the chances of accidents will also increase.

The East China Sea is a region with a large marine traffic, and any pollution incidents can quickly and widely spread because of the presence of the Kuroshio Current. These can then reach environmentally important marine areas such as the coral reefs near the Ryuku Island Chain (Qiao *et al*., 2019; NOC, 2018).

The Langrangian drift of oil added value product represents the trajectories of oil spills in the North Atlantic and Kuroshio Current regions. The product focuses on two case studies:

1) Golden trader oil spill event: An oil spill incident that occurred on the 10th of September 2011. A collision with a fishing vessel took place off the west coast of Denmark, ~40

km SW of Ringkobing Fjord. The substance spilt was bunker fuel (IFO), and the Swedish coast was impacted, more precisely the Swedish island of Tjörn (Pålsson et al., 2017). For further details see the RB document.

2) Sanchi oil spill event: The 6th of January 2018, Sanchi, an oil tanker, collided with a cargo ship in the East China Sea (Qiao *et al*., 2019). When Sanchi sank on 14th January 2018 (16:45 local time) HFO was spilled. The first island to be impacted was Takarajima (part of the Tokara Islands), at the end of January, on the 28th (Chen *et al*., 2019; Pan *et al*., 2020). The other island to be badly affected was Amami (and the adjacent southern islands) where oil was reported to land on the 1st of February (Pan *et al*., 2020). Contamination also affected Kikaijima and Tokunojima.

The products generated are the following:

- Hourly outputs of horizontal 2D oil drift in the North Atlantic at 15m during 14 days initialized on 10/09/2011 approximately 40 km off the western coast of Denmark as a continuous release of particles every hour:
    - 20110901000000-WOC-L4-CURlag_15m-NATL_OIL_SPILL_DRIFT_1H_CONT-v2.0-fv1.0.nc
- Hourly outputs of horizontal 2D oil drift in the Kuroshio region 15m during 16 days initialized on 14/01/2018 at the East China Sea as a continuous release of particles every hour:
    - 20180114000000-WOC-L4-CURlag_15m-KUR_OIL_SPILL_DRIFT_1H_CONT-v2.0-fv1.0.nc

The preliminary results obtained are generated using the version 2 velocity product which only include velocity fields at 15m. In some cases this velocity is enough to represent the test cases, but in future versions the surface dynamics (wind effects and Stokes drift) will be added, together with specific oil drift behaviour to improve the simulated trajectories. For further details on the validation see the ATBD (https://docs.google.com/document/d/1H5mSHvurVQvzrE1zfoSNMa6_CEK7qJ1eHKRoK8J0HRM/edit#).

3.2 Algorithm

3.2.1 Retrieval methodology

The Lagrangian drift of oil is simulated using the OceanParcels framework (www.OceanParcels.org). OceanParcels is an open-source software, which has been developed by Utrecht University (Netherlands) to simulate the dispersion of plastic material in the ocean. The frontend of the OceanParcels framework is written in python, and has a back-end written in C for speed and efficiency. The Parcels code (**P**robably **A** **R**eally **C**omputationally **E**fficient **L**agrangian **S**imulator) consists of a set of Python classes and methods to create customisable particle tracking simulations using output from Ocean Circulation models. Version 2.3 of Parcels is used here (Delandmeter & van Sebille, 2019).

The processing followed in the generation of the data is shown in fig. 5.

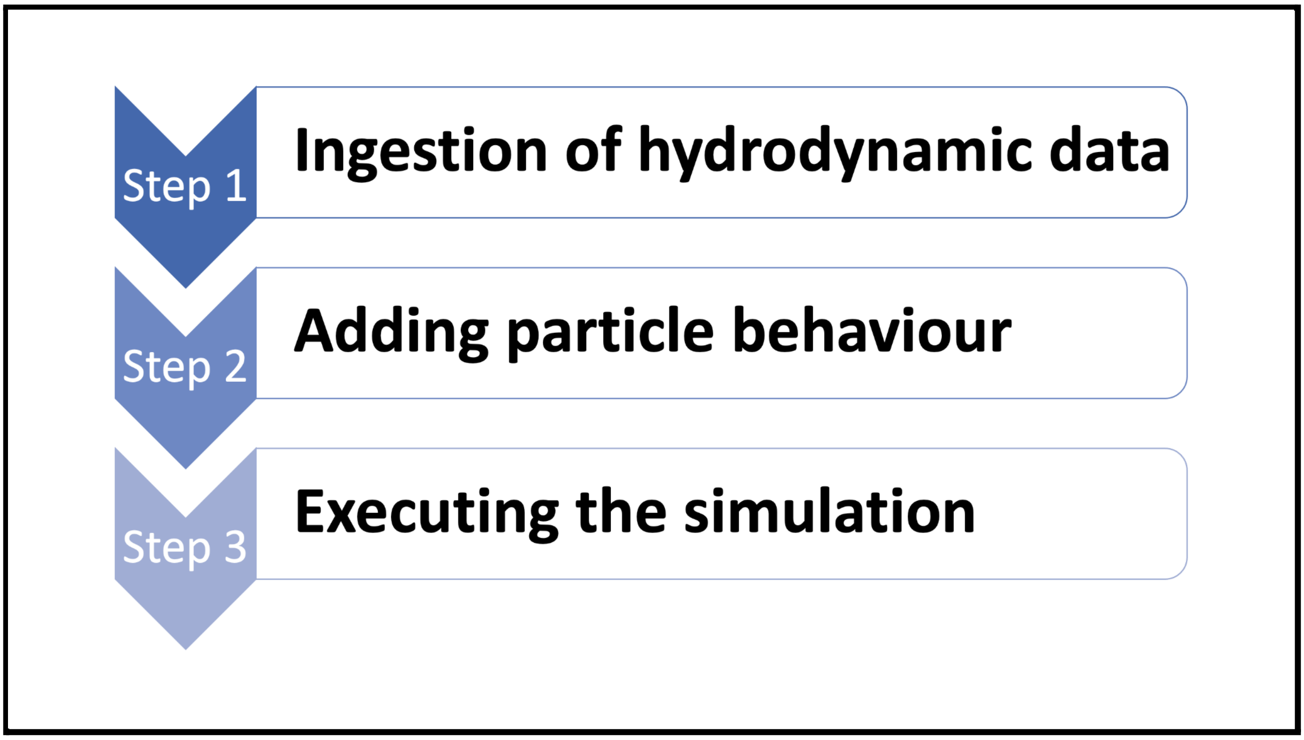


Figure 5. Flowchart describing the processing followed to generate the Surface Lagrangian drift simulations of oil.

The ocean parcels software uses the velocity fields to advect particles and simulate their trajectories. The velocity field inputs can be in different formats, and here we use netCDFs. The velocity fields used are a combination of satellite and drifter data. The data is available from 2010 to 2020, has a spatial resolution of 1/4°, an hourly temporal resolution and is available at 15m depth. The spatial resolution of 1/4° is due to the fact that the satellite geostrophic velocities from CMEMS and the ERA5 wind data have this spatial resolution, and it also provides a light product which can have a greater spatial coverage. Here we focus on the velocity data generated for two regions : the Atlantic region and the Kuroshio Current region, for the years 2011 and 2018, respectively. For more information on the input data see :
https://docs.google.com/document/d/1qVwZfxmd9iQF2YL1ZYGjmgVqo0oSnqUu_HCWmQ94fDk/edit

The particles' (oil in this case) behaviour is represented here as a Lagragian drift, by horizontally advecting them (in 2D) using the ingested velocity fields. The velocity fields used here include geostrophic currents, inertial oscillations and Ekman transport. In this second version (v2.0) preliminary simulation of the product, we assume the oil follows the total velocity of the new currents product at 15m. This allows us to first understand the particles' trajectories with this new velocity field, and in next versions the surface dynamics (wind effects and Stokes drifts) will be added as well as the oil particles' behaviour.

The main kernel is the horizontal advection of particles. The new velocity product includes two components: a geostrophic and an ageostrophic (Ekman transport and inertial oscillations) one. This to velocity fieldsets are included in the advection kernel. Particles which reach the ocean boundaries of the domain are deleted using the DeleteParticle function.

Trajectories are integrated using a two-dimensional fourth-order Runge-Kutta scheme with an integration time step of 10 minutes. The 2D position of each particle is stored every hour. A jupyter-notebook example of the code is shown in fig. 6.

```
[14]: def DeleteParticle(particle, fieldset, time):
          particle.delete()
```

2.4. Particle Set:

```
[12]: pset_v2 = ParticleSet(fieldset=fieldset_total, pclass=JITParticle, lon=lons, lat=lats, time=timep, repeatdt=repeatdt) #, depth=depp
```

3. Executing the simulation:

3.1. Defining parameters

```
[5]: file_name = "test03_v02_ATL_Sep2011_cont1h_MESH.nc"
```

```
[15]: output_file = pset_v2.ParticleFile(name=file_name, outputdt=timedelta(hours=1))
```

3.2. Running

```
[16]: pset_v2.execute(pset_v2.Kernel(AdvectionRK4), runtime=timedelta(days=14.), dt=timedelta(minutes=10),
                   recovery={ErrorCode.ErrorOutOfBounds: DeleteParticle}, output_file=output_file)

      start_time = timep.isoformat()
      time_unit_out= "seconds since " + str(pset_v2.time_origin)
      end_time = (num2date(output_file.lasttime_written, time_unit_out)).isoformat()

      add_WOC_nc_attbts(output_file, start_time, end_time, -75.0, 20., 48., 80.
              , input_filename="WOC-L4-CUReul-ENATL-1H: runconv15m_enatl2_d*.nc'"
              , ntitle="North Atlantic 2D horizontal drift of Oil spill for ESA WOC project"
              , summary="This dataset contains the positions of virtual particles released hourly from 10/09/2011 to 25/09/2011 at 15m representin
              , inid = "NATL_OIL_SPILL_DRIFT_1H_CONT"
              , ndepth = "15")

      output_file.export()  # exports the trajectory data to a netcdf file
```

Figure 6. Example of kernel set-up for the execution of the oil spill simulation for scenario 1 (Golden Trader).

Once the hydrodynamic input data and particle behaviour kernels are reading, the simulations can be run and saved as netCDFs. To do so, a set of parameters need to be decided:

- **Timestep (dt)** : 10 minutes
- **Repeat dt :**
  - Case 1 (Golden Trader scenario) : 1 hour throughout the simulation
  - Case 2 (Sanchi scenario) : 1 hour until the 23rd of January 2018 (following ITOPF's specifications)
- **Output timestep (dt) :** Hourly
- **Simulation length:**
  - Case 1 (Golden Trader scenario) : 14 days
  - Case 2 (Sanchi scenario) : 16 days
- **Initial positions and release dates :**
  - Case1 (Golden Trader scenario) : Positions of released particles are shown on fig. 7., at the approximate location of the oil spill event.

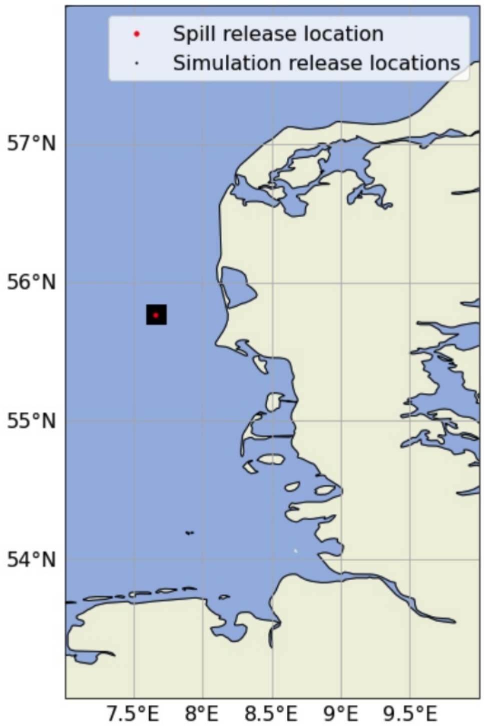
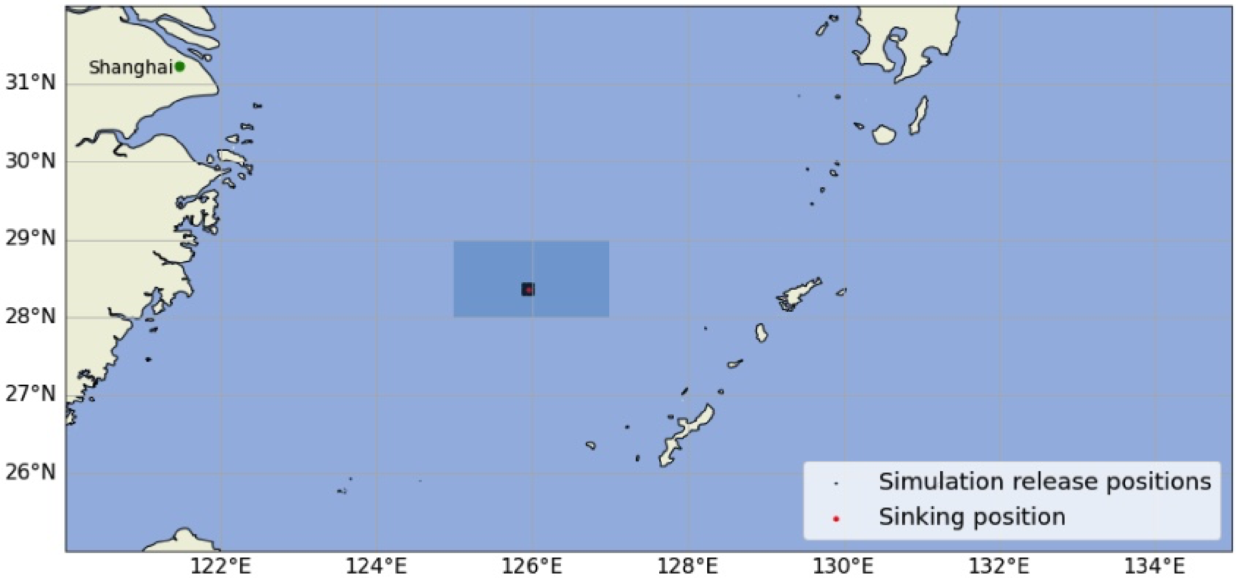


Figure 7. Release locations of the virtual particles representing the Location of the Golden Trader oil spill which took place on the 10/09/2011 off the western coast of Denmark. The red dot shows the exact position where the oil spill took place, and the black dots are the release locations of the virtual particles around the red point.

- Case 2 (Sanchi scenario) : Positions of released particles are shown on fig. 8., at the approximate location of the oil spill event.



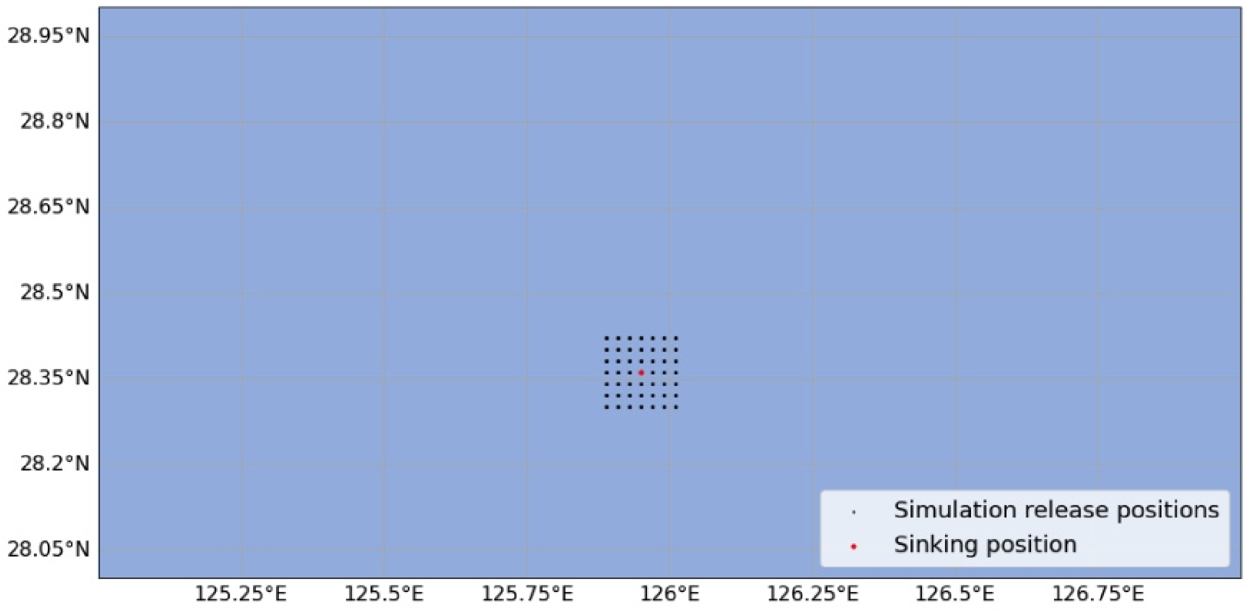


Figure 8. Top: Release locations of the virtual particles representing the Sanchi oil spill which took place on the 14/01/2018 at the East China Sea. Bottom: Zoom in the blue box shown in the top plot. The red dot shows the exact position where the oil spill took place, and the black dots are the release locations of the virtual particles around the red point.

3.2.2 Limitations

In this preliminary simulation of version 2.0 of the product, data is generated using the version 2 velocity product which only includes velocity fields at 15m. In some cases this velocity is enough to represent the test cases, but in future versions the surface dynamics (wind effects and Stokes drift) will be added, together with specific oil drift behaviour to improve the simulated trajectories.

The ageostrophic component of the currents is now available as separate components, so it is no longer a limitation in order to test in the next version the effect of different components (e.g. inertial oscillations and Stokes drift). On the other hand, the new currents product is only available at one depth (15m), so the vertical displacement of the particles, and its effect on the horizontal displacement cannot be so easily implemented.

3.2.3 Differences with previous version

- Parcels version used in v1.0 was 2.2.2 and now version 2.3. The updates of the new parcels version can be found here : https://github.com/OceanParcels/parcels/releases/tag/v2.3.0
- A new case study in a new region (Kuroshio Current) is included: the Sanchi oil spill during January 2018.
- For the Golden Trader oil spill scenario, the release time and locations are refined. Particles every 1 hour instead of every 3 hours and the location release is now more precise, following the indications of the user (ITOPF).

3.3 Product Description

3.3.1 Spatial information

The trajectories of the oil spill are obtained in the North Atlantic and Kuroshio region for case 1 and 2, respectively. The spatial resolution is representative of the spatial resolution of the hydrodynamic data used (1/4°).

3.3.2 Temporal information

This data is generated for the years 2011 and 2018 for scenario 1 (Golden Trader oil spill) and 2 (Sanchi oil spill), respectively. The position of the virtual particles representing the oil spill are generated every hour. The scenario 1 simulation is run for 14 days, and for 16 days in scenario 2, until most of the oil spill is expected to have already beached / landed.

3.3.3 Product content

Table 3. Product information for oil spill simulations.

Dataset name	Parameter usual name	Variable name	units
• 20110901000000-WOC-L4-CURlag_15m-NATL_OIL_SPILL_DRIFT_1H_CONT-v2.0-fv1.0.nc • 20180114000000-WOC-L4-CURlag_15m-KUR_OIL_SPILL_DRIFT_1H_CONT-v2.0-fv1.0.nc	time	time	seconds since 1970-01-01
	trajectory: Unique identifier for each particle	trajectory	-
	latitude	lat	degrees_north
	longitude	lon	degrees_east
	depth	z	metres (positive down)

3.3.4 File name convention

The filename convention followed is:

<Indicative Date><Indicative Time>-WOC-<Processing Level>-<Parameter>-<Product String>-v< Product Version>-fv<File Version>.<File Type>

Where:

- Indicative Date: date of the release of the first particle in YYYYmmdd format
- Indicative Time: time of the release of the first particle in HHMMSS format
- Processing Level: level here is L4
- Parameter: CURlag_15m here (Currents Lagrangian drift at 15m depth)
- Product String: gives information on the simulation (depth, region, particle type, temporal resolution and particle release type), e.g. NATL_OIL_SPILL_DRIFT_1H_CONT
- Product Version: For example, v2.0 here

- File Version: For example, fv.10 here
- File Type: 'nc' as, as explained in section 3.3.5, files are saved in netCDF format so 'nc'

3.3.5 File format

The files are saved in NetCDF4 format. As they are 2D lagrangian simulations, the dimensions are trajectory and observation. Trajectory is the unique identifier for each virtual particle and observation indicates the number of observations (positions of the particles) obtained, and is equivalent to time.

3.3.6 Metadata

Table 4. Metadata description of oil spills simulation output files.

Element name	**Description**
standard_name_vocabulary	The source of the standard name table
title	A short description of the dataset.
license	Licensing policy (open)
tracking_id	A UUID allowing this file to be uniquely referenced back against other information in a database, providing complete provenance on request
keywords	A comma separated list of key words and phrases.
id	The file name
history	An audit trail for modifications to the original data.
naming authority	Identifies a namespace provider
creation_date	Time of file creation date_created
creator_name creator_email	The data creator's name, URL, and email. The "institution" attribute will be used if creator_url the "creator_name" attribute does not exist.
project	The scientific project that produced the data.
time_coverage_start	Describe the temporal coverage of the data as a time range.
time_coverage_end time_coverage_duration time_coverage_resolution	
processing_level	A textual description of the processing level

	of the data.
geospatial_lat_min geospatial_lat_max geospatial_lat_resolution geospatial_lon_min geospatial_lon_max geospatial_lon_resolution	Describe a simple latitude, longitude, and vertical bounding box.