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BioSpace25 - Biodiversity insight from Space
10 - 14 February 2025 | ESA-ESRIN | Frascati - Italy



Predicting species distributions in the open ocean

Using satellite-derived environmental data and convolutional neural networks

Gaétan Morand¹, Alexis Joly², Tristan Rouyer¹,
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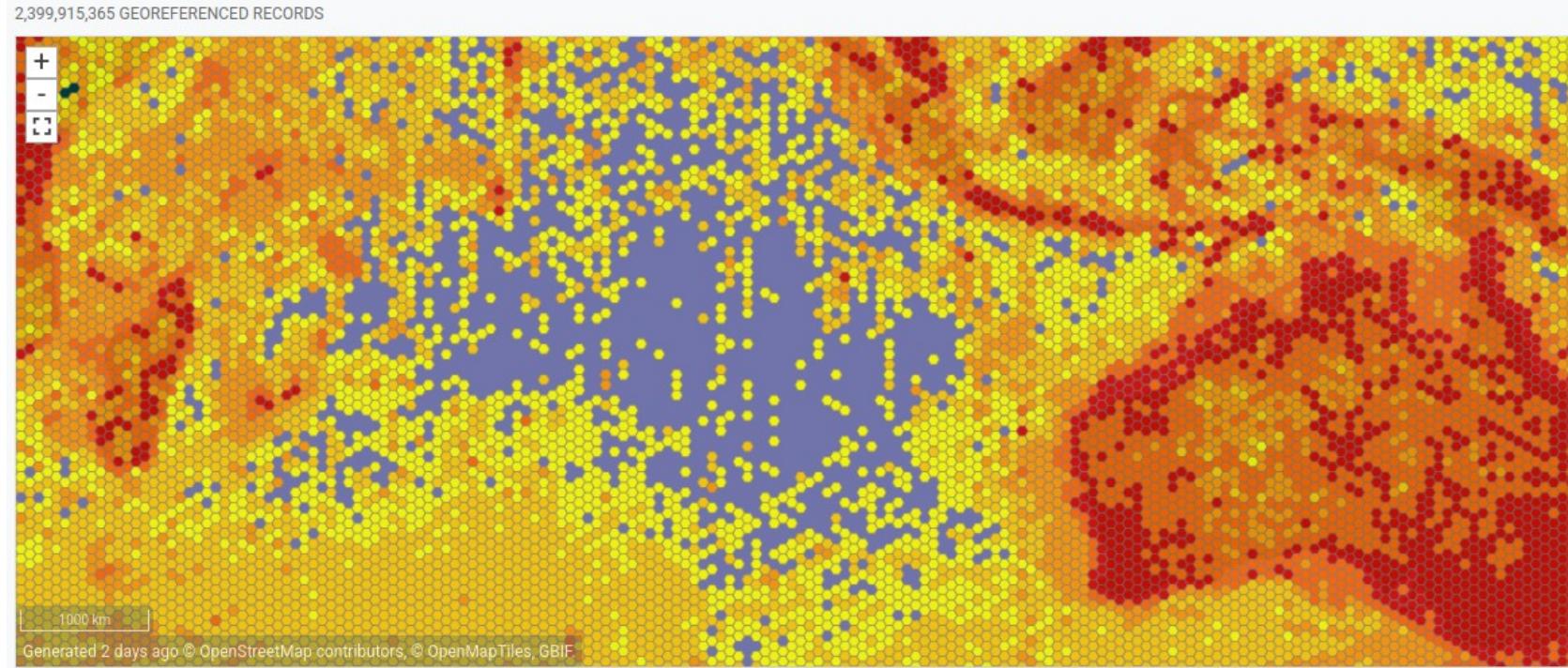
Introduction: what data?



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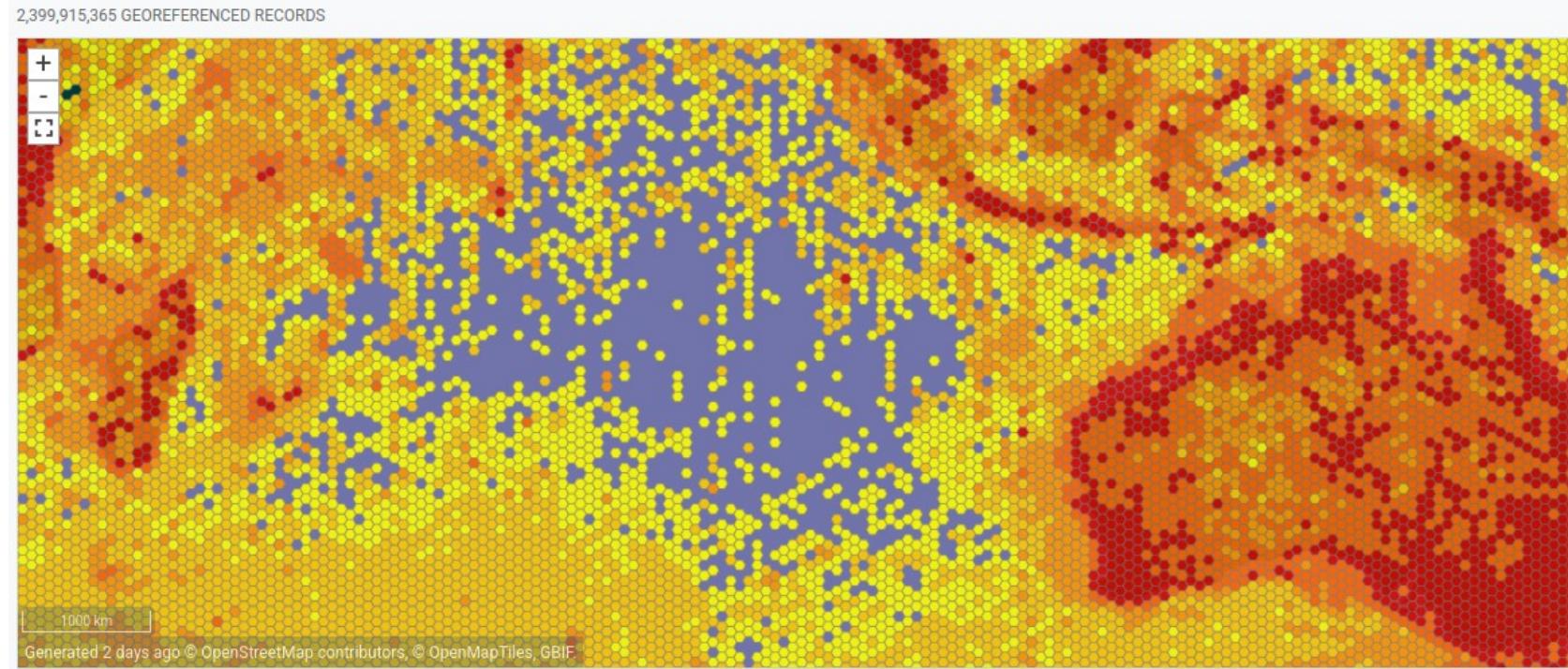
Introduction: what data?



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Models cannot use coordinates as predictors
Hypothesis: same environmental conditions = same species

Limitation in usual SDMs: number of predictors

=> Only one value per variable

Point of observation	Buffer around observation
Value	Average (+ STD, min, max)

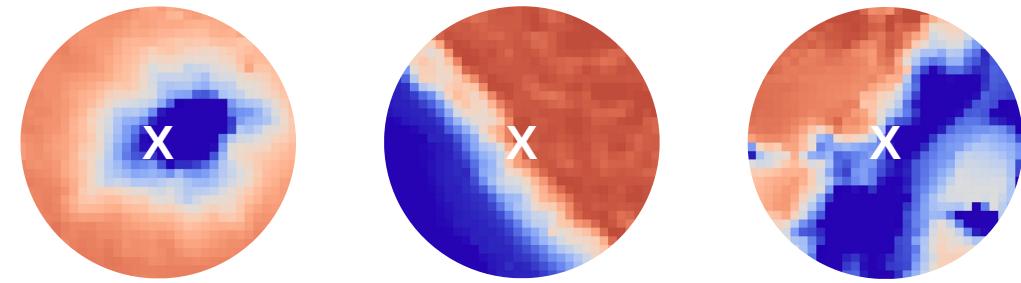
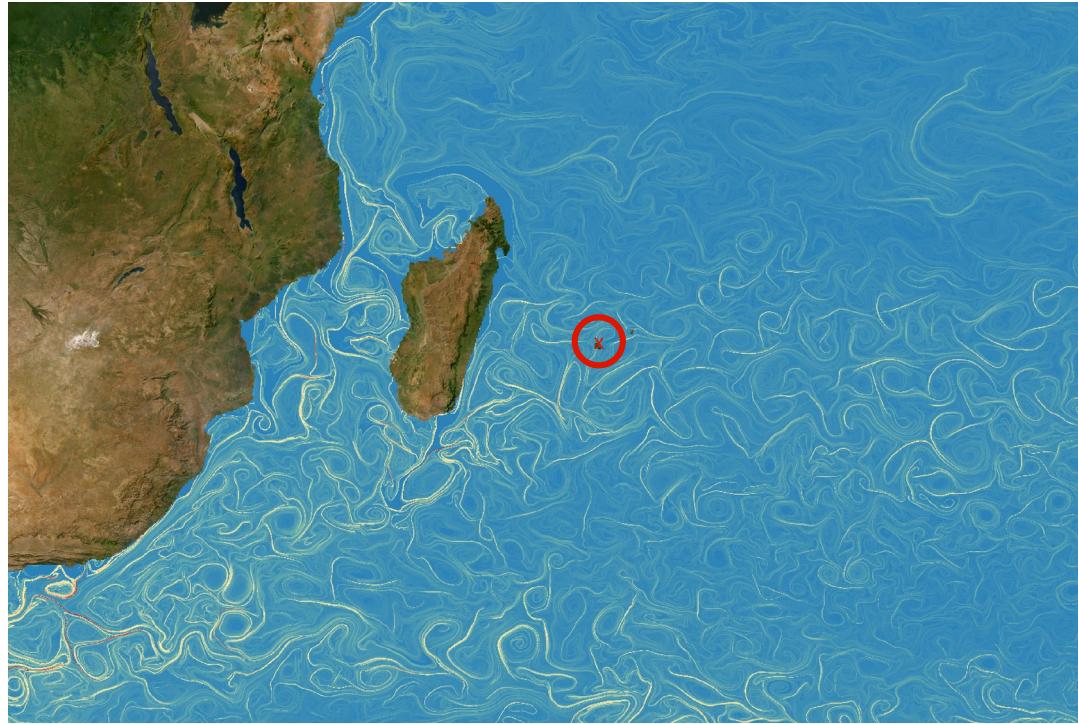
Environmental landscape



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Spatial structure IS important



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SDMs: Chosing environmental data



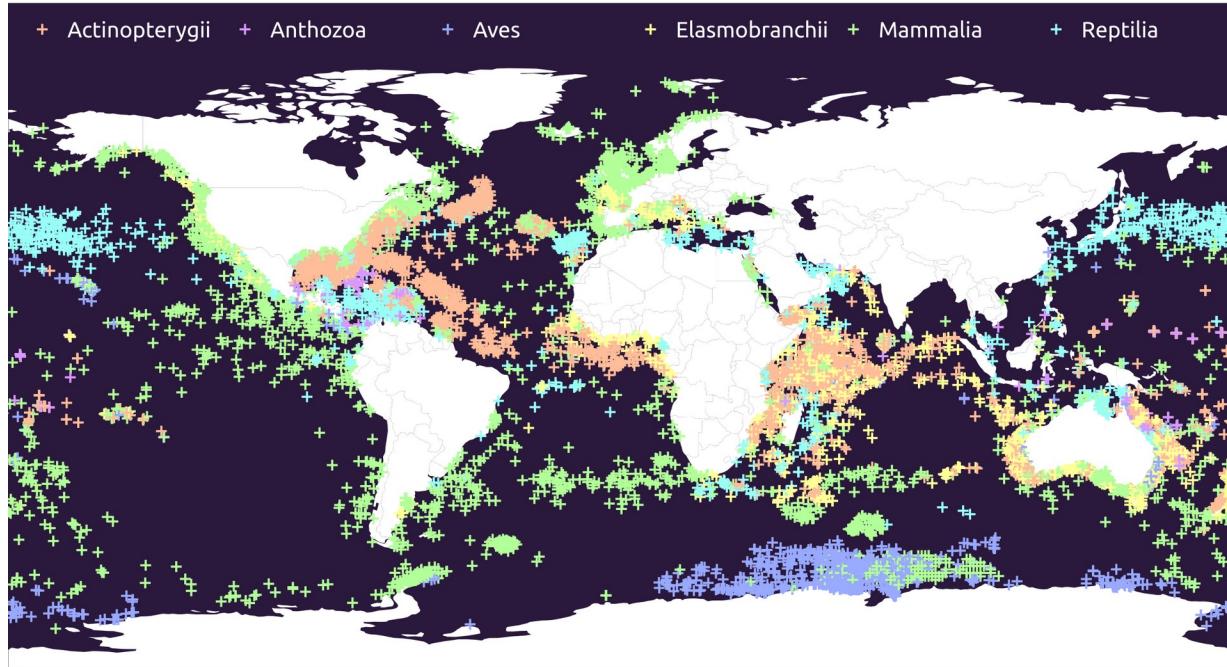
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Point of observation	Buffer around observation	Environmental landscape
Value	Average (+ STD, min, max)	Spatially structured data

Pilot study



38 genera

300,000 occurrences

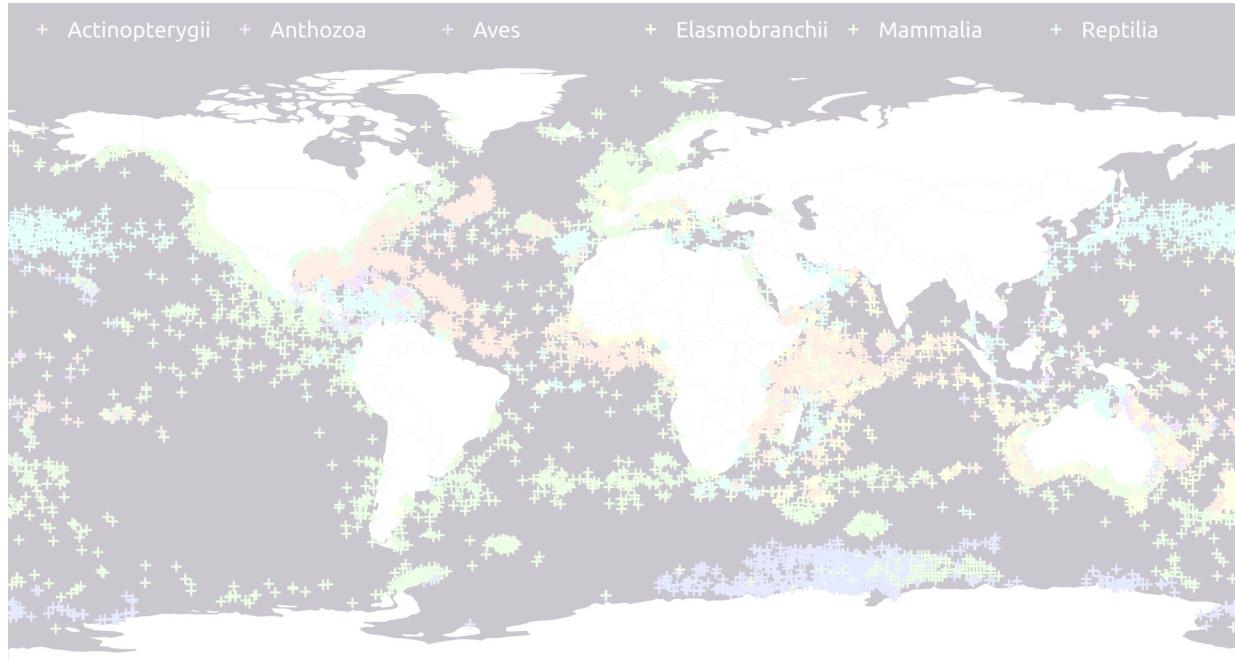


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Pilot study



38 genera

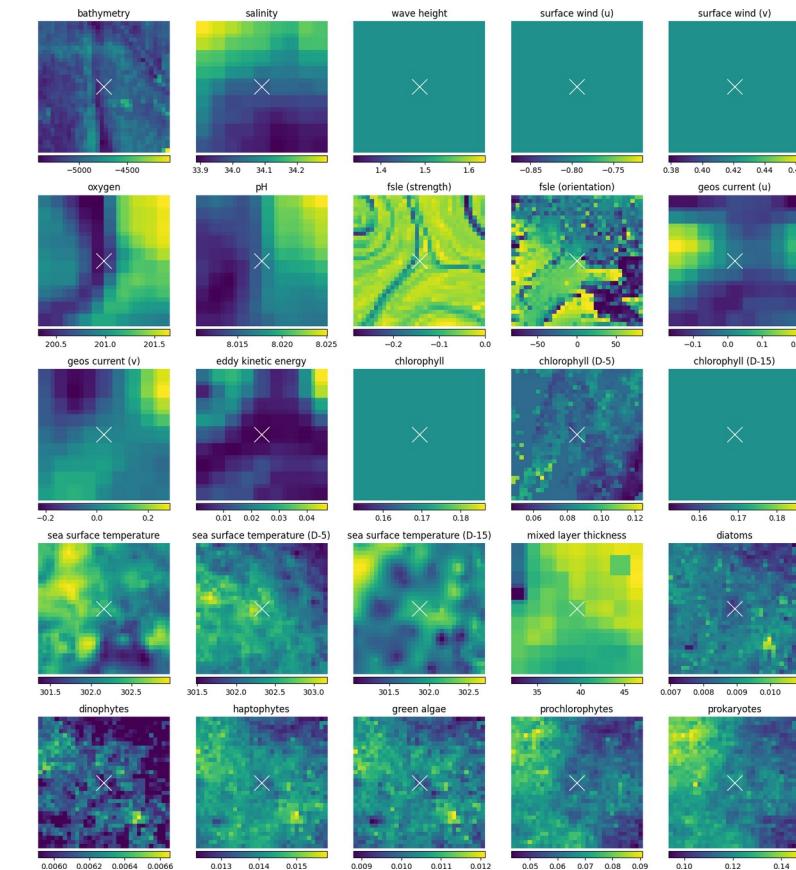
300,000 occurrences



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18 variables

geoenrich 0.6.5

pip install geoenrich



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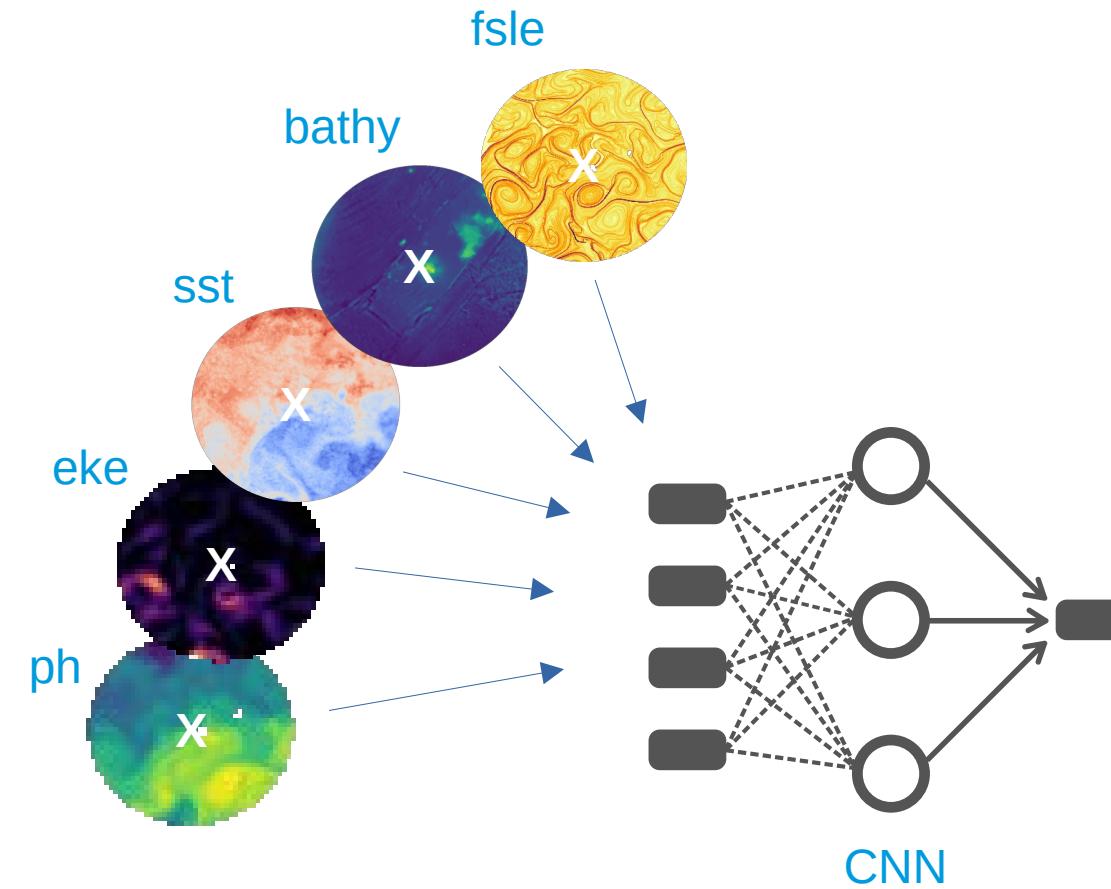
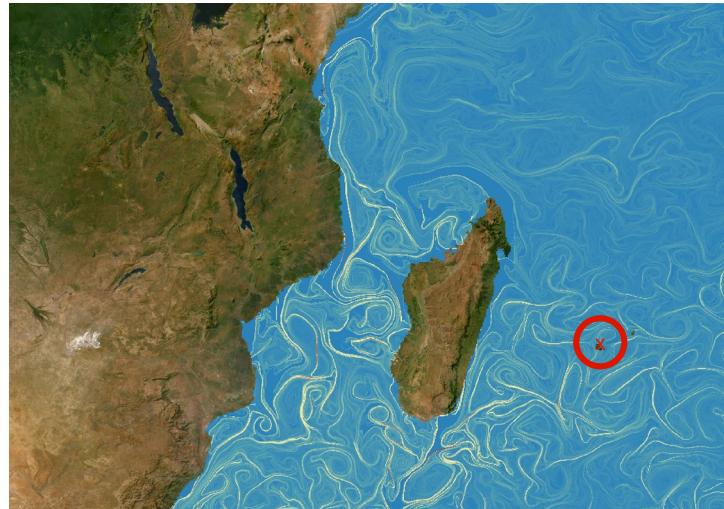
Spatial data processing



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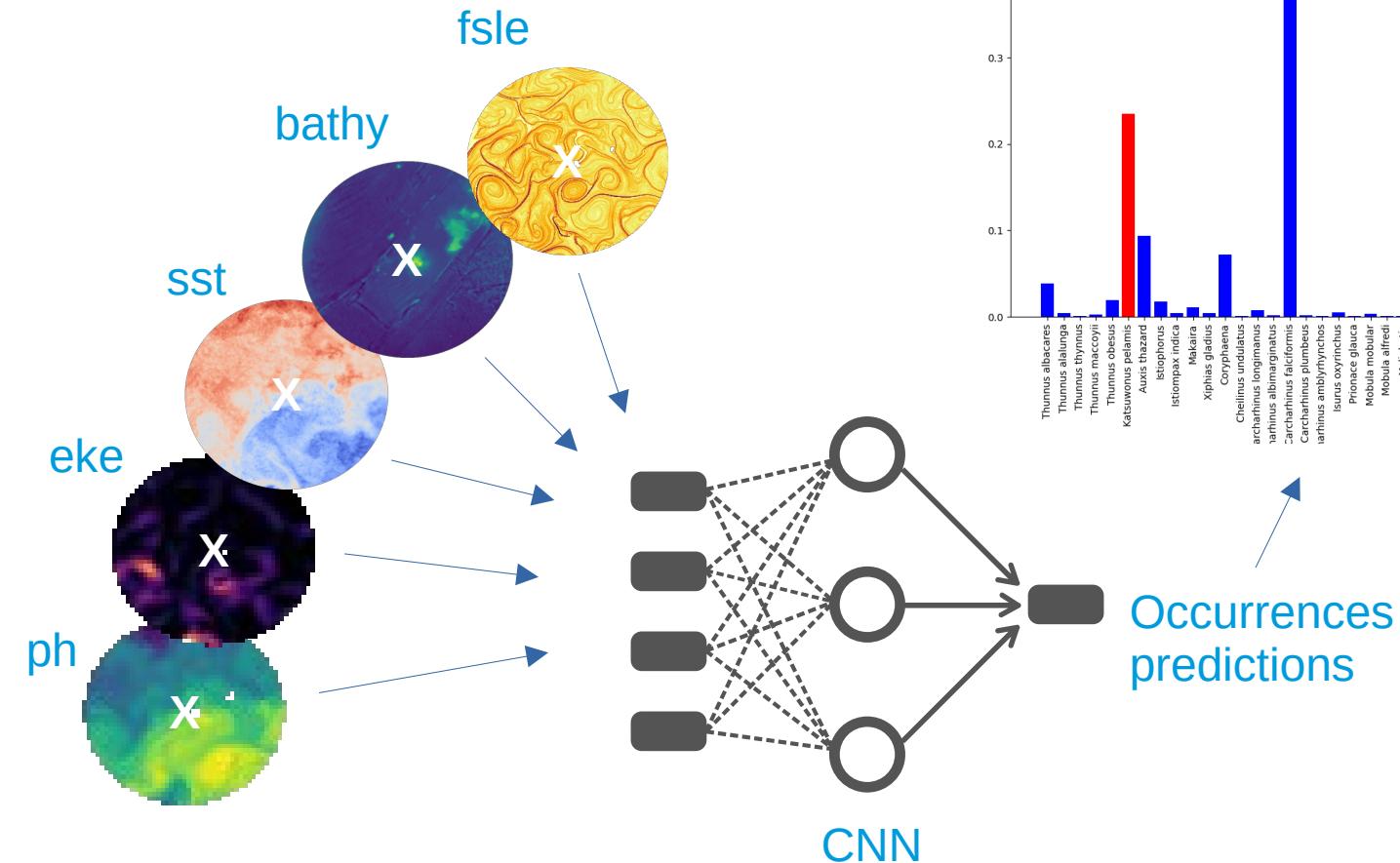
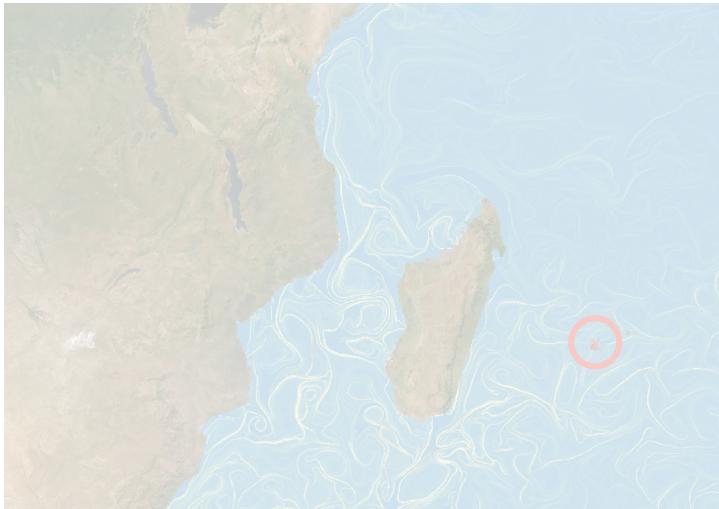
Spatial data processing



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Results



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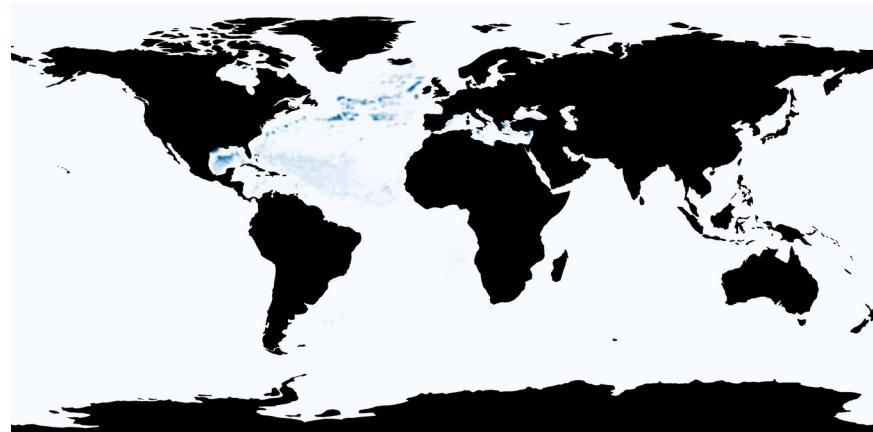
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Variation in space



Puffinus pacificus



Thunnus thynnus

Variation in time



Prionace glauca

Model performance



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True label	Predicted label																																						
	Thunnus albacares	Thunnus alalunga	Thunnus thynnus	Thunnus macrourus	Thunnus obesus	Katsuwonus pelamis	Auxis thazard	Istiophorus	Istiophax indica	Makara	Xiphias gladius	Coryphaena	Cheilinus undulatus	Carcharhinus longimanus	Carcharhinus albimarginatus	Carcharhinus falciformis	Carcharhinus plumbeus	Carcharhinus amblyrhynchos	Iurus oxyrinchus	Prionace glauca	Mobula mobular	Mobula alfredi	Myliobatis	Megaptera novaeangliae	Balaenoptera physalus	Balaenoptera musculus	Tursiops	Stenella longirostris	Delphinus delphis	Physeter macrocephalus	Phocoena phocoena	Eubalaena australis	Chelonia mydas	Caretta caretta	Eretmochelys imbricata	Aptenodytes forsteri	Puffinus pacificus	Acropora	
Thunnus albacares	0.19	0.11	0.12	0	0.09	0.02	0.01	0.01	0	0.02	0.12	0.19	0	0	0.03	0.01	0	0	0.02	0.04	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0					
Thunnus alalunga	0.03	0.04	0.09	0	0.1	0.02	0	0	0	0.01	0.09	0.06	0	0	0	0	0	0	0.02	0.08	0	0	0	0	0	0	0.01	0	0.01	0	0	0	0	0					
Thunnus thynnus	0.04	0.1	0.09	0	0.05	0.01	0	0	0	0	0.09	0.06	0	0	0	0	0	0	0	0	0.01	0	0.01	0	0.01	0	0	0	0.01	0	0	0	0	0	0				
Thunnus macrourus	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.07	0.05	0	0	0.01	0	0	0.01	0	0	0	0	0.01	0	0	0	0	0			
Thunnus obesus	0.04	0.24	0.09	0	0.28	0.01	0	0	0.01	0.01	0.06	0	0	0.01	0.01	0	0	0.01	0.05	0	0	0	0	0	0	0.03	0	0	0	0	0	0	0						
Katsuwonus pelamis	0.03	0.01	0.02	0	0.02	0.07	0.06	0	0	0	0.02	0.03	0	0	0	0.05	0	0	0.01	0.01	0	0	0.01	0	0	0	0	0.01	0	0	0	0	0	0					
Auxis thazard	0	0	0	0	0	0.05	0.01	0	0	0	0.01	0	0	0	0	0.07	0	0	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
Istiophorus	0.01	0	0	0.01	0	0.01	0.01	0	0.01	0	0	0	0.03	0.08	0.01	0	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0						
Istiophax indica	0.05	0	0	0	0.01	0.02	0.09	0	0	0.09	0	0.03	0.06	0.05	0.16	0	0	0.19	0.2	0	0	0	0	0	0	0.01	0.01	0	0.01	0.01	0	0	0						
Makara	0.03	0	0	0.11	0.03	0.02	0.02	0	0.43	0	0	0.01	0.02	0.03	0	0	0.12	0.12	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0	0						
Xiphias gladius	0.08	0.16	0.12	0	0.1	0	0	0	0	0.31	0.18	0	0	0	0	0.01	0.01	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0						
Coryphaena	0.07	0.13	0.1	0	0.06	0.02	0.02	0	0	0.17	0.34	0	0	0	0.03	0.01	0	0	0	0	0	0	0	0	0.01	0	0	0.01	0	0	0	0							
Cheilinus undulatus	0	0	0	0	0	0	0	0	0	0	0.71	0	0.01	0	0	0.03	0	0	0.03	0	0	0	0.01	0.07	0	0	0	0.01	0	0.06	0	0.01	0.06						
Carcharhinus longimanus	0.02	0	0	0.09	0	0.04	0.01	0	0.07	0	0	0.02	0.05	0.05	0.01	0	0.14	0.32	0.02	0	0.07	0	0	0.01	0.01	0	0	0.01	0.01	0	0	0.01	0						
Carcharhinus albimarginatus	0.01	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0.01	0.04	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
Carcharhinus falciformis	0.01	0	0	0	0	0.01	0.03	0.05	0.05	0	0	0.01	0	0	0.25	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
Carcharhinus plumbeus	0.01	0	0	0	0	0	0	0.06	0	0	0	0	0	0.04	0	0.05	0	0	0	0	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0					
Carcharhinus amblyrhynchos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
Iurus oxyrinchus	0.03	0	0	0.01	0.04	0	0.01	0	0.04	0	0	0.01	0.01	0	0	0	0.01	0.15	0	0	0.02	0	0.01	0	0	0.01	0	0.02	0	0.01	0	0	0						
Prionace glauca	0.01	0	0	0	0.03	0	0	0	0.02	0	0	0.01	0	0	0	0	0.09	0.72	0	0	0.03	0.01	0.01	0.02	0	0	0.01	0	0	0	0	0	0	0					
Mobula mobular	0	0	0.05	0	0	0.01	0.02	0.01	0	0	0.03	0.01	0	0.02	0	0	0	0.01	0.01	0.03	0	0.01	0.02	0.01	0	0	0.01	0.04	0.01	0	0	0							
Mobula alfredi	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0.02	0	0	0	0.03	0	0	0	0	0	0	0	0.01	0	0.01	0	0.01	0					
Myliobatis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0.08	0	0	0	0.02	0	0	0	0	0.01	0	0.01	0	0.02	0					
Megaptera novaeangliae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0.01	0.77	0	0.04	0.01	0.02	0.01	0	0.04	0.01	0	0.01	0.01	0.01	0						
Balaenoptera physalus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.71	0	0	0	0.04	0.02	0.04	0	0	0.01	0	0	0	0	0	0				
Balaenoptera musculus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0	0	0	0.03	0.02	0.83	0	0.01	0.02	0.02	0	0.01	0	0	0	0	0				
Tursiops	0	0	0	0	0	0.01	0	0	0	0.01	0	0	0	0	0	0	0.01	0	0	0.02	0.01	0	0.01	0.04	0.01	0	0	0	0	0	0	0	0	0					
Stenella longirostris	0	0	0	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.07	0	0	0	0.01	0.02	0	0.02	0.01	0	0					
Delphinus delphis	0.01	0.01	0	0	0.04	0.04	0.01	0	0	0	0	0	0	0	0	0	0.02	0	0	0.01	0.02	0.04	0.03	0.03	0.63	0.07	0.03	0	0.01	0	0.01	0	0	0					
Physeter macrocephalus	0.01	0	0	0.02	0.02	0	0	0	0	0.01	0.01	0	0	0	0	0	0.02	0	0	0	0.01	0.04	0.01	0.02	0.06	0.64	0.01	0.07	0	0.01	0	0.01	0	0	0.01				
Phocoena phocoena	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.03	0	0	0.02	0	0	0.06	0	0.08	0	0	0	0	0	0	0	0				
Eubalaena australis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.03	0.02	0.05	0	0.07	0	0	0	0	0	0	0	0	0	0				
Chelonia mydas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0.01	0.02	0	0	0.02	0.05	0	0.02	0.01	0	0	0	0	0				
Caretta caretta	0.01	0.01	0	0	0.01	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0.02	0	0	0.01	0.04	0.03	0.01	0	0.01	0	0.01	0	0	0						
Eretmochelys imbricata	0	0	0	0	0	0	0	0.03	0	0	0	0.02	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0.01	0.02	0	0.01	0.01	0.02	0	0.01	0	0					
Aptenodytes forsteri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.99	0	0	0	0	0	0				
Puffinus pacificus	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0.02	0	0.01	0	0.01	0	0.01	0	0.01	0	0.01	0				
Acropora	0	0	0	0	0	0	0	0.04	0	0	0.01	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0



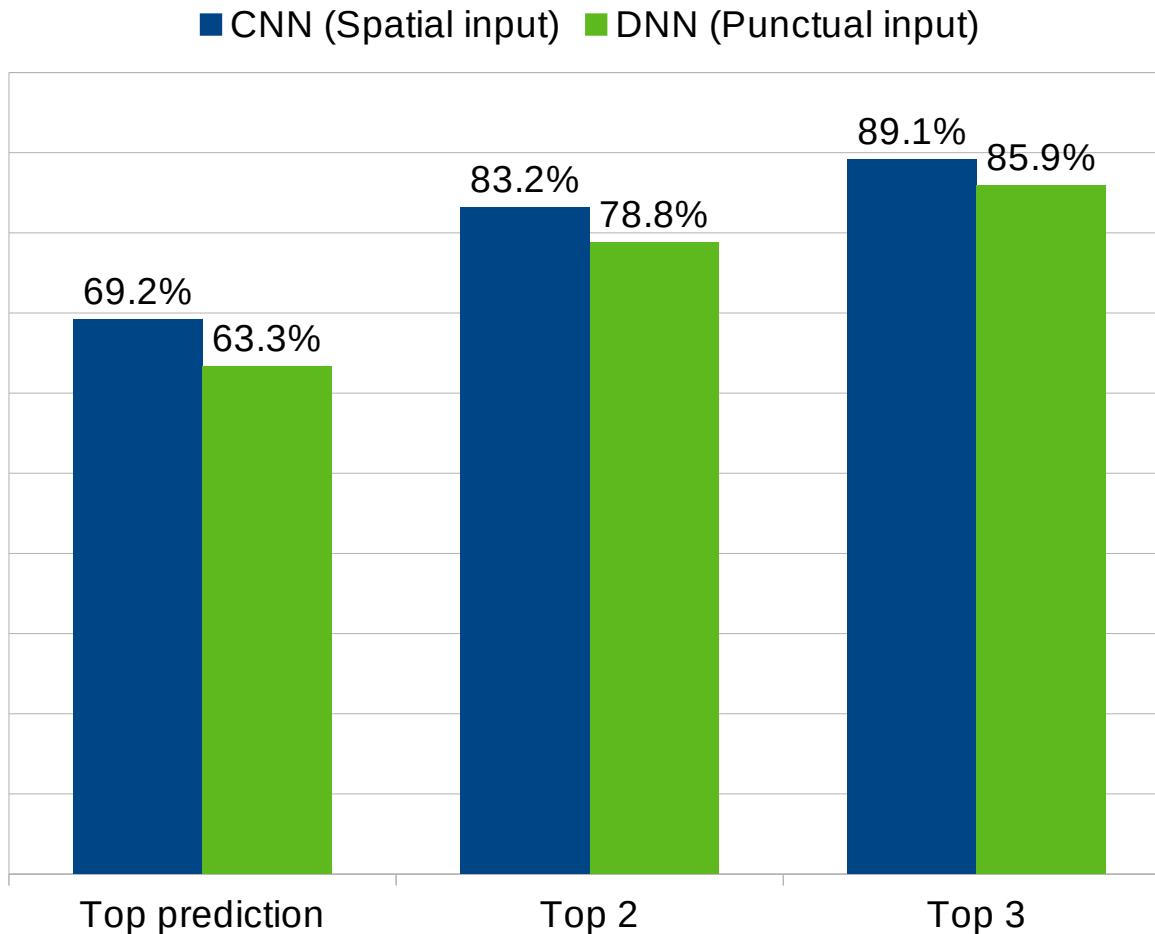
Model performance



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Most important insight



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Predictive power

Influence of variables

Most important insight



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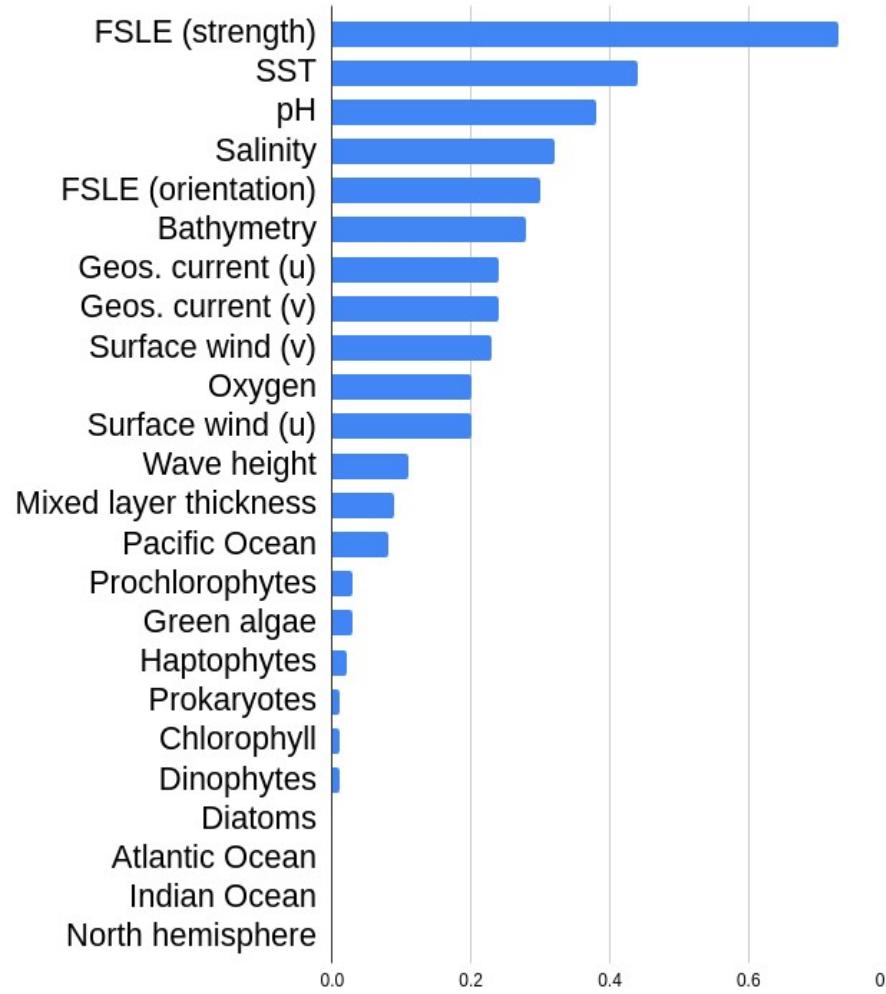
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Predictive power

Influence of variables

Median integrated gradient



Thank you



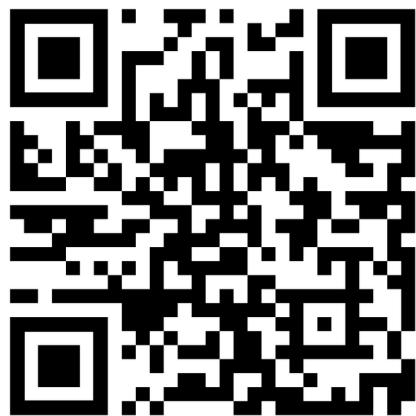
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Peer Community Journal

Section: Ecology



Predicting species distributions in the open ocean with convolutional neural networks

Gaétan Morand^{✉,1}, Alexis Joly^{✉,2}, Tristan Rouyer^{✉,1}, Titouan Lorieul^{✉,2}, and Julien Barde^{✉,1}

Contact: gaetan.morand@umontpellier.fr

Future work:

Include multiple modalities in the model: satellite imagery and scalar time series.

Recommendations for data producers:

- Maintain data access protocols in the long term
- Maximize duration and geographical coverage

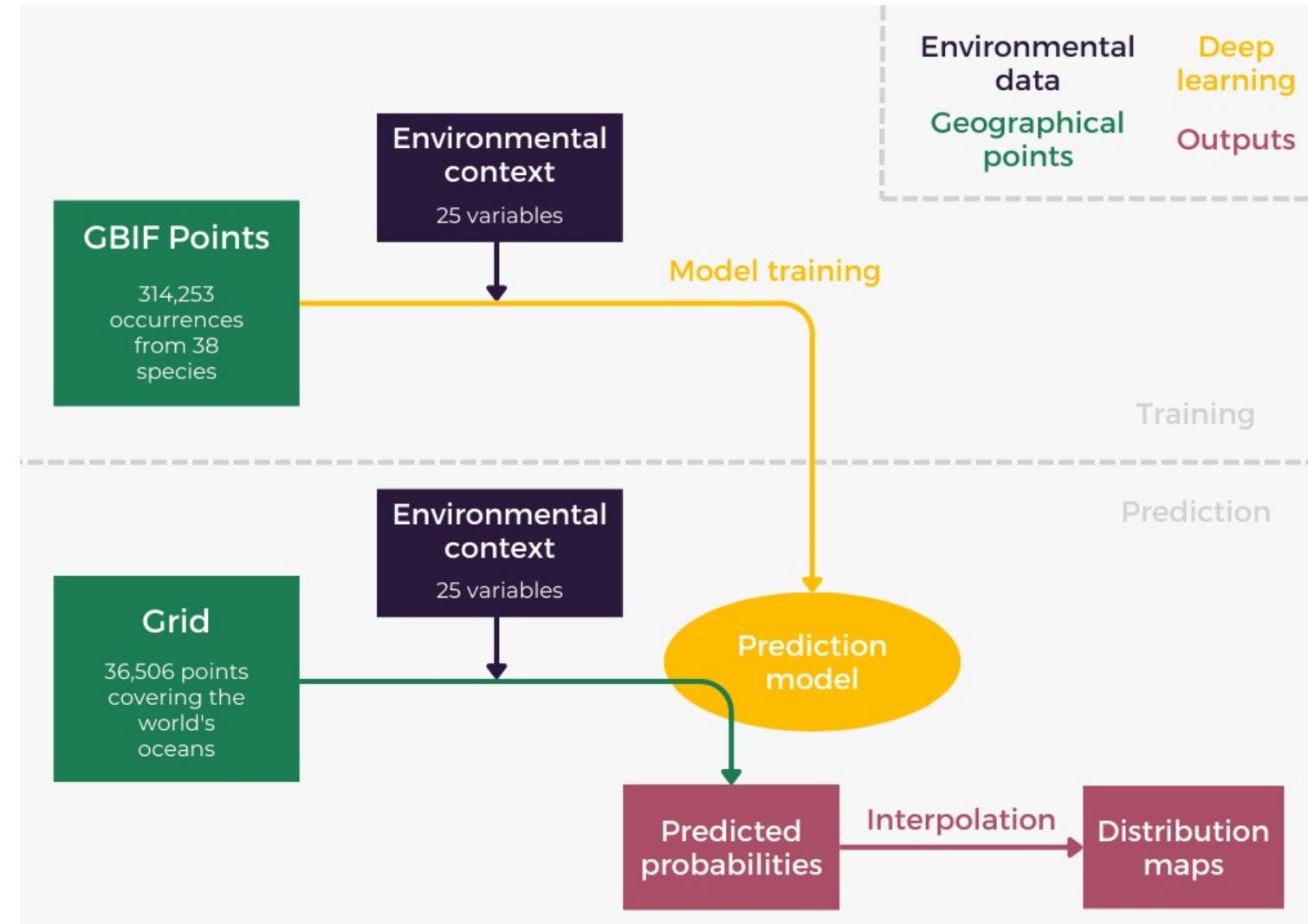
Appendix: Pipeline



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Appendix: Genera



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English name	Taxonomic name	N samples	DOI				
Yellowfin tuna	<i>Thunnus albacares</i>	9,998	10.15468/dl.gr2wbb				
Longfin tuna	<i>Thunnus alalunga</i>	9,991	10.15468/dl.aqjv3y				
Atlantic bluefin tuna	<i>Thunnus thynnus</i>	8,908	10.15468/dl.nnyeyb				
Southern bluefin tuna	<i>Thunnus maccoyii</i>	2,022	10.15468/dl.tw97qj				
Bigeye tuna	<i>Thunnus obesus</i>	9,999	10.15468/dl.c96qpp				
Skipjack tuna	<i>Katsuwonus pelamis</i>	9,986	10.15468/dl.6y2zzm				
Frigate Tuna	<i>Auxis thazard</i>	4,855	10.15468/dl.kfm6kq				
Sailfish	<i>Istiophorus</i>	9,996	10.15468/dl.f48dug				
Black marlin	<i>Istiompax indica</i>	705	10.15468/dl.b5acky				
Blue marlin	<i>Makaira</i>	2,767	10.15468/dl.sygtaw				
Swordfish	<i>Xiphias gladius</i>	9,996	10.15468/dl.hazqd2				
Dolphinfish	<i>Coryphaena</i>	9,992	10.15468/dl.q67bqt				
Humphead wrasse	<i>Cheilinus undulatus</i>	2,446	10.15468/dl.9g76hq				
Oceanic Whitetip	<i>Carcharhinus longimanus</i>	2,160	10.15468/dl.b5ws4q				
Whitetip	<i>Carcharhinus albimarginatus</i>	9,991	10.15468/dl.vpc772				
Silk shark	<i>Carcharhinus falciformis</i>	9,998	10.15468/dl.vg4rwh				
Sandbar shark	<i>Carcharhinus plumbeus</i>	9,993	10.15468/dl.7fczpa				
Grey reef shark	<i>Carcharhinus amblyrhynchos</i>	10,000	10.15468/dl.ccqyws				
Mako shark	<i>Isurus oxyrinchus</i>	6,240	10.15468/dl.h5akxk				
Blue shark	<i>Prionace glauca</i>	9,973	10.15468/dl.zqkssk				
Devil ray	<i>Mobula mobular</i>	1,064	10.15468/dl.p4e2sx				
Reef manta	<i>Mobula alfredi</i>	7,928	10.15468/dl.bkjkgu				
Eagle ray	<i>Myliobatis</i>	9,974	10.15468/dl.3u3v7k				
	Humpback whale			<i>Megaptera novaeangliae</i>	9,980	10.15468/dl.yzg4n3	
	Fin whale			<i>Balaenoptera physalus</i>	9,996	10.15468/dl.r9kaq8	
	Blue whale			<i>Balaenoptera musculus</i>	9,973	10.15468/dl.28f7xd	
	Bottlenose			<i>Tursiops</i>	9,952	10.15468/dl.bec9p4	
	Spinner dolphin			<i>Stenella longirostris</i>	7,394	10.15468/dl.xz5eds	
	Common dolphin			<i>Delphinus delphis</i>	9,974	10.15468/dl.u5be7v	
	Sperm whale			<i>Physeter macrocephalus</i>	9,984	10.15468/dl.7pf4ue	
	Harbour porpoise			<i>Phocoena phocoena</i>	9,937	10.15468/dl.afr2fn	
	Southern right whale			<i>Eubalaena australis</i>	9,963	10.15468/dl.e3hdkj	
	Green turtle			<i>Chelonia mydas</i>	9,835	10.15468/dl.6gs9rp	
	Loggerhead			<i>Caretta caretta</i>	9,941	10.15468/dl.dmb6ds	
	Hawksbill turtle			<i>Eretmochelys imbricata</i>	9,721	10.15468/dl.e6w44w	
	Emperor penguin			<i>Aptenodytes forsteri</i>	9,981	10.15468/dl.s5unhs	
	Wedge-tailed shearwater			<i>Puffinus pacificus</i>	9,964	10.15468/dl.vyztue	
	Acropora coral			<i>Acropora</i>	8,676	10.15468/dl.vg752f	



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Appendix: Variables



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Variable	Source	Source type	Res.	Time Res.	Unit
Bathymetry	GEBCO, 2022	Observations	0.0042°		m
Salinity	European Union-CMS, 2020	Observations	0.25°	weekly	P.S.U.
Wave Height	European Union-CMS, 2021b	Observations	2°	daily	m
Surface wind (u)	CCMP (Mears et al., 2022)	Observations	0.25°	6 hours	$m.s^{-1}$
Surface wind (v)	CCMP (Mears et al., 2022)	Observations	0.25°	6 hours	$m.s^{-1}$
Oxygen	European Union-CMS, 2018, 2019	Models	0.25°	daily	$mmol.m^{-3}$
pH	European Union-CMS, 2018, 2019	Models	0.25°	monthly	
FSLEs (strength)	LOCEAN/CLS/CTOH/CNES, 2021	Observations	0.04°	daily	$days^{-1}$
FSLEs (orientation)	LOCEAN/CLS/CTOH/CNES, 2021	Observations	0.04°	daily	degrees
Geostrophic Current (u)	European Union-CMS, 2017, 2021a	Observations	0.25°	daily	$m.s^{-1}$
Geostrophic Current (v)	European Union-CMS, 2017, 2021a	Observations	0.25°	daily	$m.s^{-1}$
Eddy kinetic energy	Calculated		0.25°	daily	$m^2.s^{-2}$
Chlorophyll	OCCI (Sathyendranath et al., 2021)	Observations	0.042°	daily	$mg.m^{-3}$
Chlorophyll (D-5)	OCCI (Sathyendranath et al., 2021)	Observations	0.042°	daily	$mg.m^{-3}$
Chlorophyll (D-15)	OCCI (Sathyendranath et al., 2021)	Observations	0.042°	daily	$mg.m^{-3}$
SST	MUR (NASA/JPL, 2019)	Observations	0.25°	daily	kelvin
SST (D-5)	MUR (NASA/JPL, 2019)	Observations	0.25°	daily	kelvin
SST (D-15)	MUR (NASA/JPL, 2019)	Observations	0.25°	daily	kelvin
Mixed layer thickness	European Union-CMS, 2020	Observations	0.25°	weekly	m
Diatoms	European Union-CMS, 2022	Observations	4km	monthly	$mg.m^{-3}$
Dinophytes	European Union-CMS, 2022	Observations	4km	monthly	$mg.m^{-3}$
Haptophytes	European Union-CMS, 2022	Observations	4km	monthly	$mg.m^{-3}$
Green algae	European Union-CMS, 2022	Observations	4km	monthly	$mg.m^{-3}$
Prochlorophytes	European Union-CMS, 2022	Observations	4km	monthly	$mg.m^{-3}$
Prokaryotes	European Union-CMS, 2022	Observations	4km	monthly	$mg.m^{-3}$
Atlantic Ocean	Calculated				
Indian Ocean	Calculated				
Pacific Ocean	Calculated				
North hemisphere	Calculated				

FSLE (Finite Size Lyapunov Exponents) = rate of separation of particle trajectories



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