High Resolution Soil Moisture for Agricultural Applications and Low Frequency Passive Microwave User Requirement Consolidation Study

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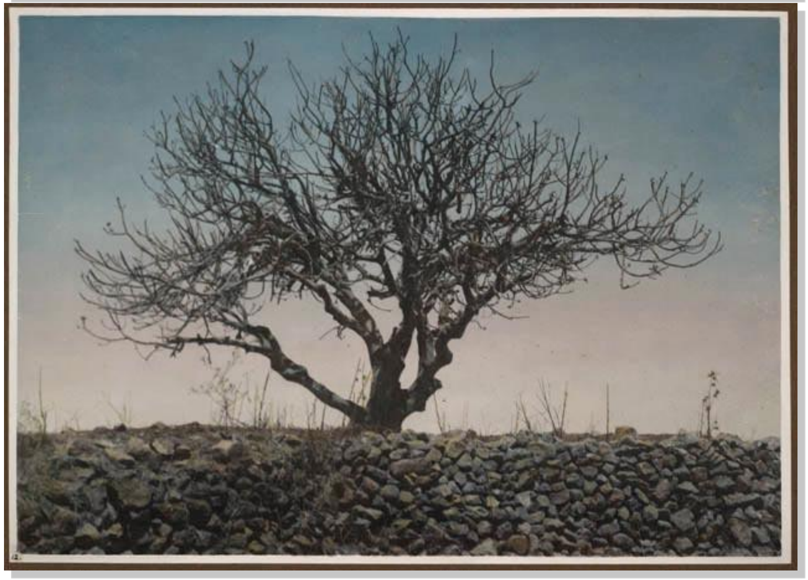
Outline

- Soil Moisture for dEsert Locust earLy Survey- **SMELLS project**
- REC: Crop irrigation management by multi-sensor remote sensing approach
- Low Frequency Passive Microwave User Requirement Consolidation Study

Scientific Justification

SMELLS project introduces the use of Soil Moisture to preventive management of Desert Locust.

Those plagues have threatened agricultural production in Africa, the Middle East and Asia for centuries and regularly affect up to one-tenth of the world's human population.

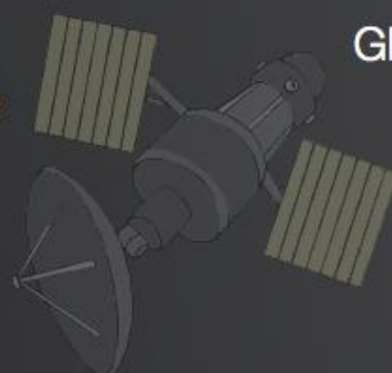


Preventive management aims to prevent or to limit crop damage by controlling populations before they can reach high densities and form mass migrating swarms.

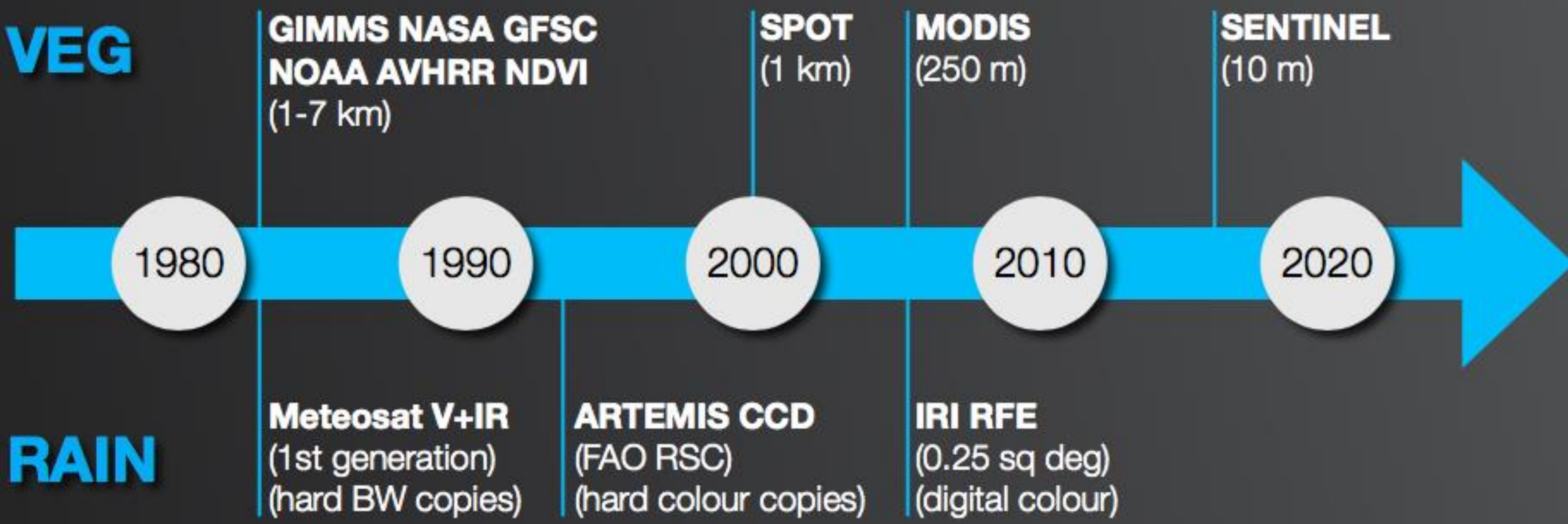
Surface to be monitored is immense latitudes 0 – 40 N, longitudes 20 W – 80 E

moist sandy soil & green vegetation

rainfall	vegetation
Meteosat	GIMMS NASA GFSC
ARTEMIS CCD	NOAA AVHRR
CMORPH RFE	SPOT
	LANDSAT
	MODIS
	SENTINEL



remote sensing evolution 1980s-2015



Objectives

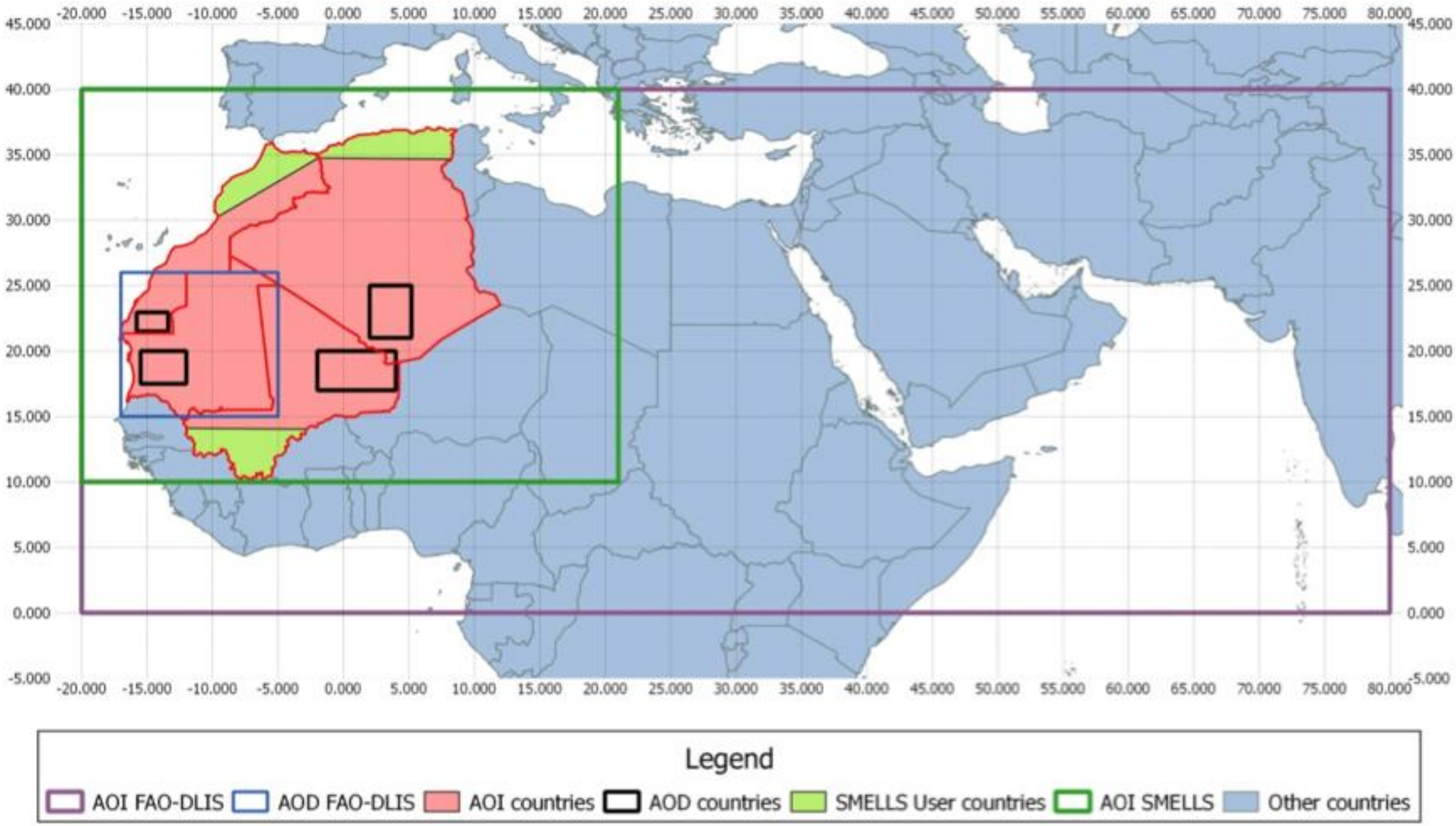
1. The establishment of a dialogue between developers and Desert Locust monitoring users about their requirements related to Soil Moisture Remote Sensing.
2. Assessing the capacity of Soil Moisture to predict Desert Locust presence to be used in the framework of Desert Locust preventive management.
3. The development of an innovative approach to derive High Resolution Soil Moisture products from Sentinel-1 in synergy with SMOS data.

Users Requirements

In accordance with Requirements Baseline defined with Users, the SMELLS project has provided Soil Moisture (SM) estimations at two spatial resolutions:

- SM at a resolution of 1km for the entire AOI based on L-band passive MW every 10 days between 2010 to 2017 and
- SM at a resolution of 100m for areas where and when Sentinel-1 acquisition is available for 2015-2016.

Users Requirements



SSM

1km / 2-3 days

L-band Passive MW SMOS/SMAP/WCOM

- accuracy 0.04 m3/m3
- low spatial resolution 40 km
- high temporal 2 - 3 d

+

Medium Resolution O/T MODIS (1 km, 1 d)

DisPATCh

SSM (1 km, 2 - 3 d)

SMELLS 1km

SSM

1km / 2-3 days

L-band Passive MW SMOS/SMAP/WCOM

- accuracy 0.04 m3/m3
- low spatial resolution 40 km
- high temporal 2 - 3 d

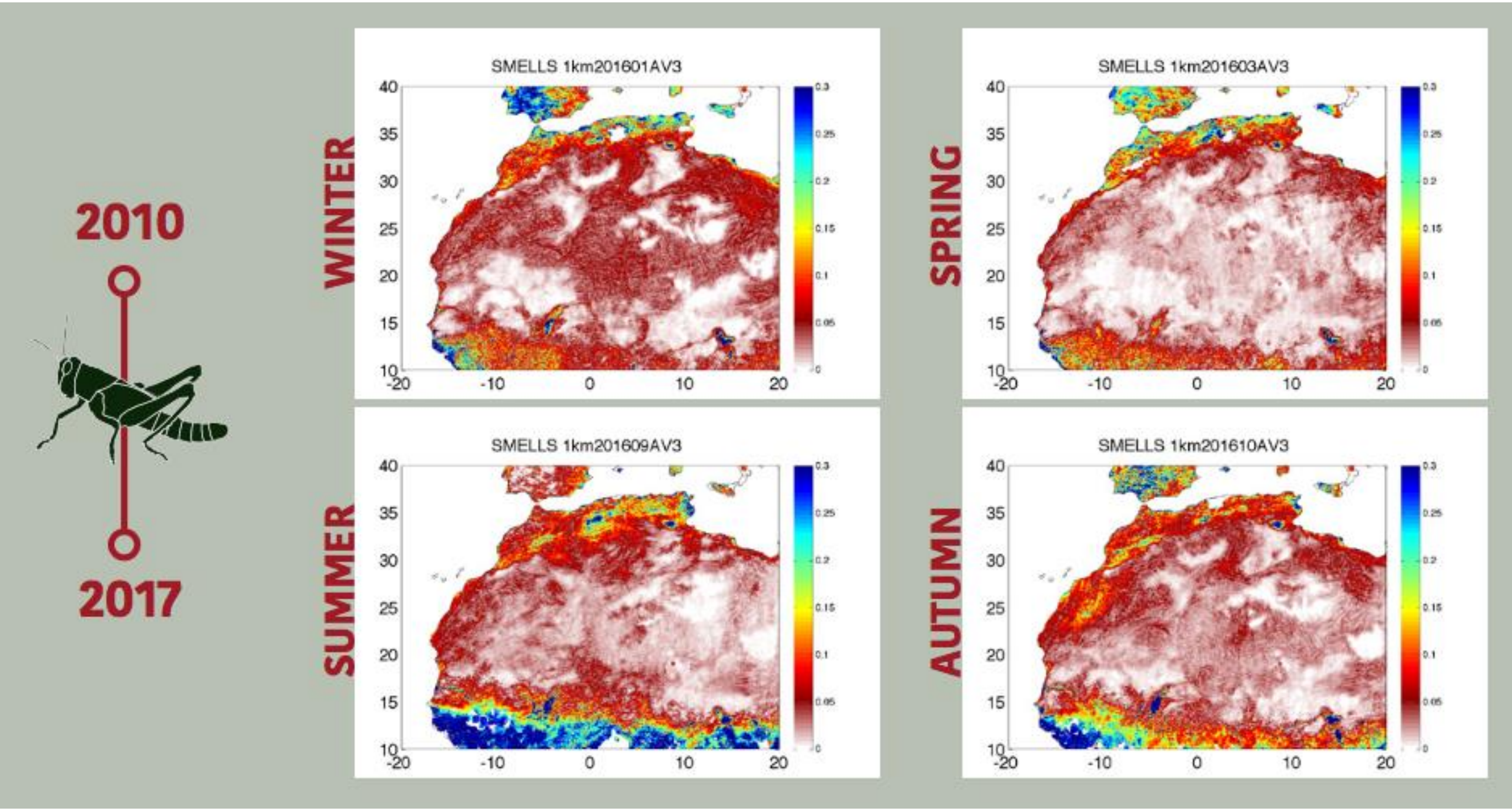
+

Medium Resolution O/T MODIS (1 km, 1 d)

DisPATCh

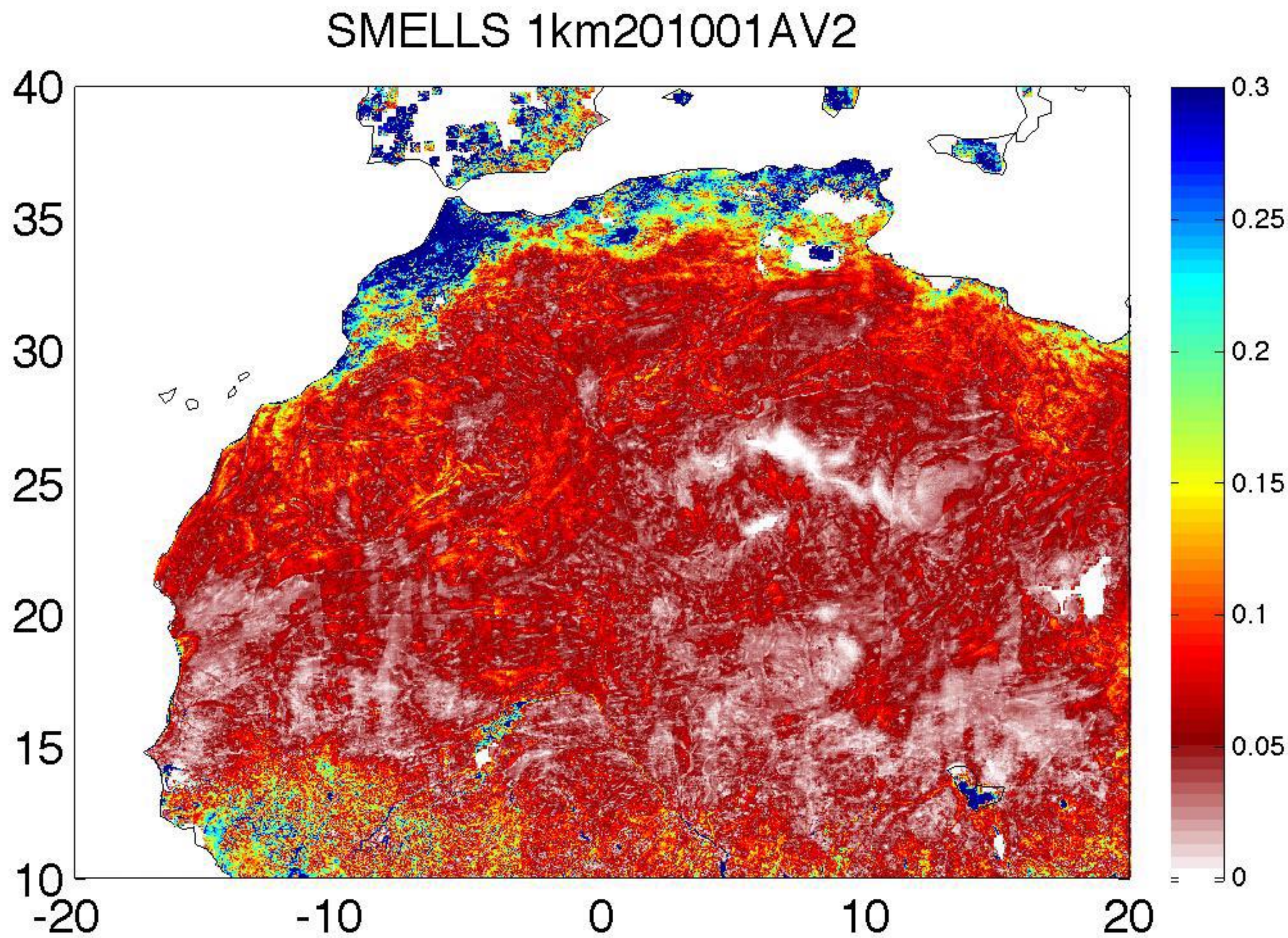
Implemented and validated in Catalonia [Merlin et al., 2013, Escorihuela et al. 2016], Central Morocco (Merlin et al. 2015), South Eastern Australia (Malbeteau et al. 2016) and USA (Molero et al. 2016)

SMELLS 1km



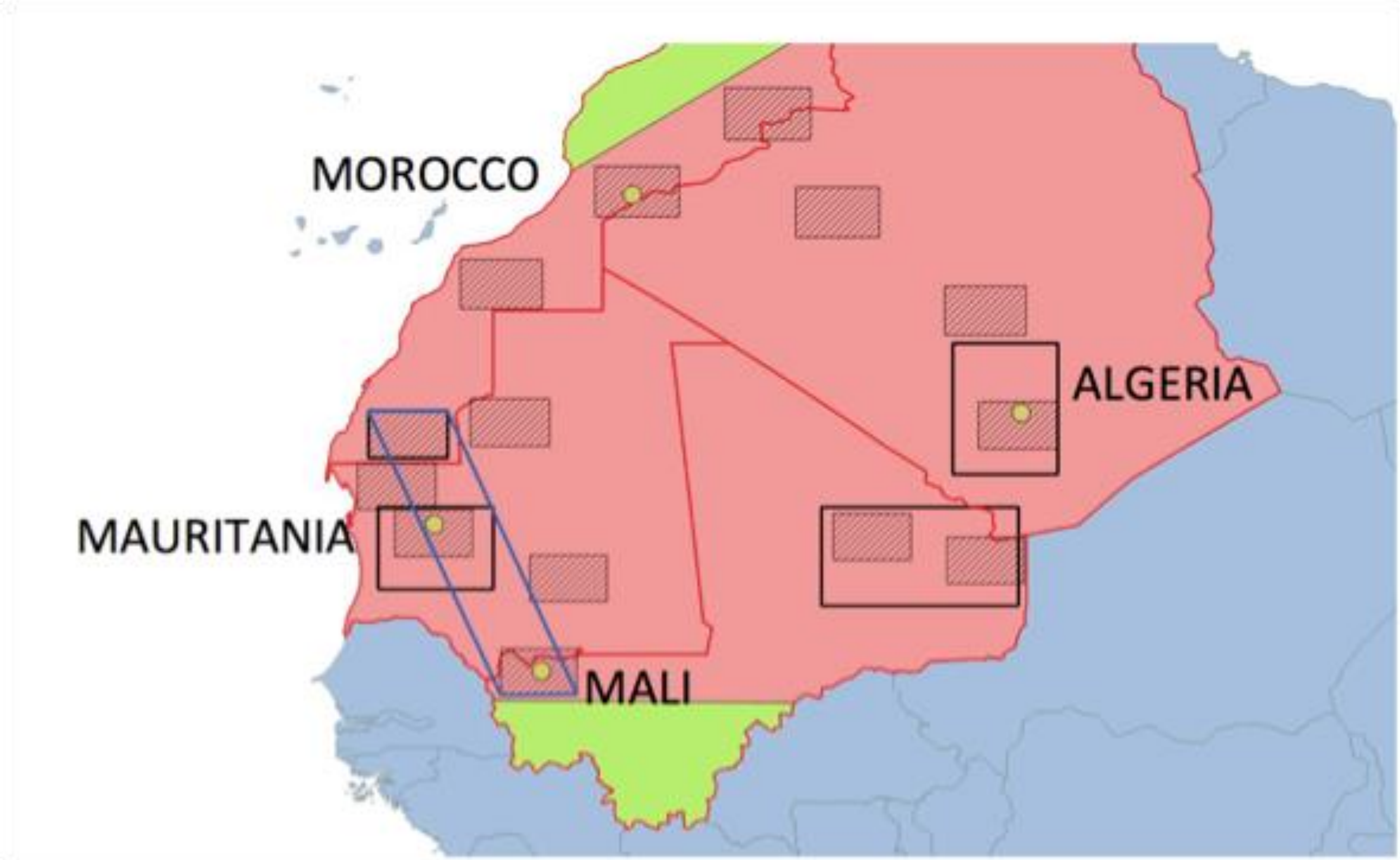
http://smells.isardsat.com/data-portal/

SMELLS 1km



SMELLS 1km201001AV2
40
35
30
25
20
15
10
-20
-10
0
10
20
0.3
0.25
0.2
0.15
0.1
0.05
0

SMELLS Soil Moisture Stations



SMELLS Soil Moisture Stations

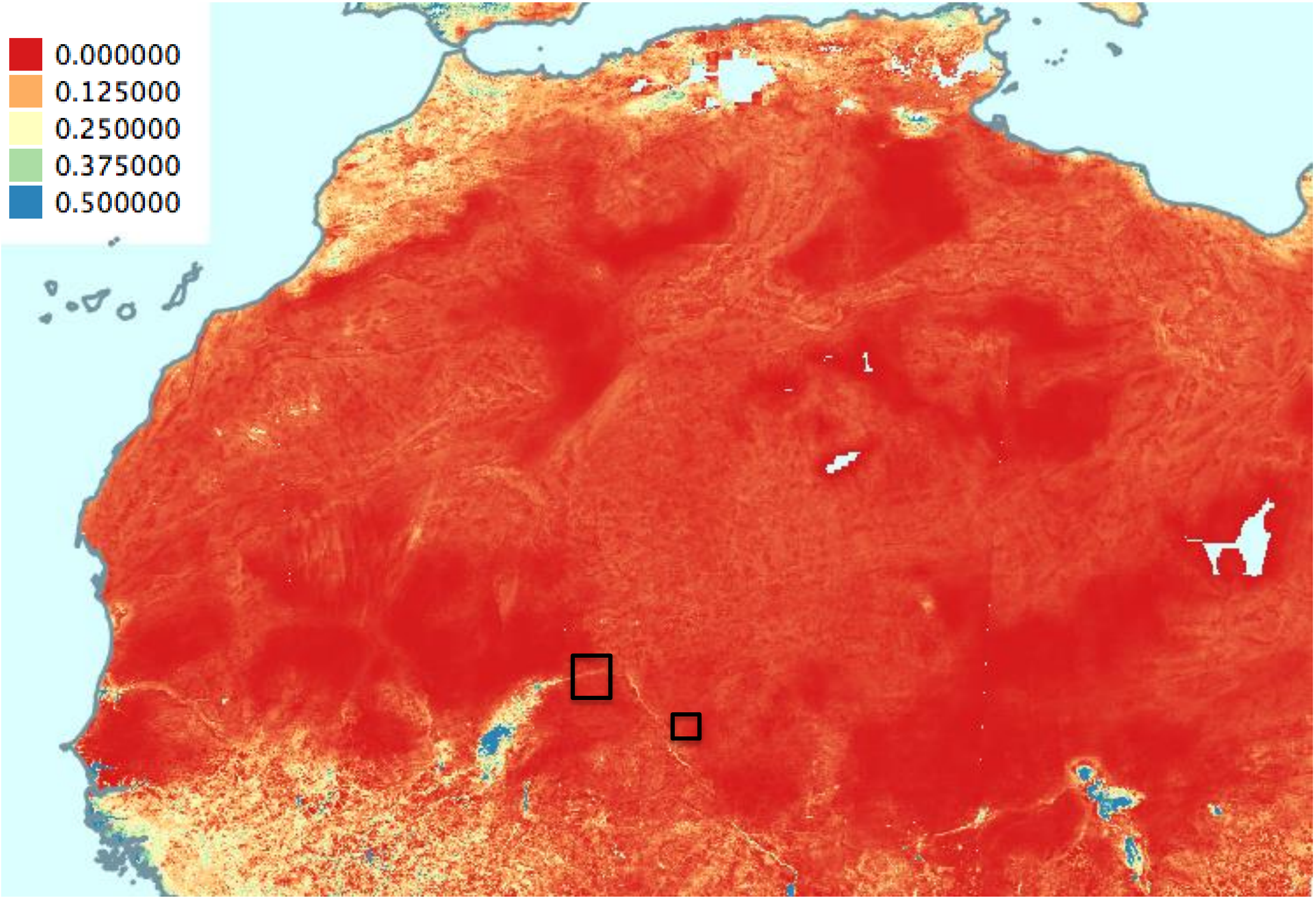
MOROCCO
Fam el Hisn, province of Guelmim-Es Semara
(Lat N 29°00'58.8", Lon W 8°50'29.9")

ALGERIA
Abalessa, province of Tamanraset
(Lat N 22°47'33.0", Lon E 4°14'41.0")

MAURITANIA
42km South-east of Akjoujt, province of Adrar
(Lat N 19°38'07.4", Lon W 14°02'03.3")

MALI
Yélimané, province of Kayes
(Lat N 15°07'11.8", Lon W 10°33'14.8")

AMMA Sites Mali and Niger



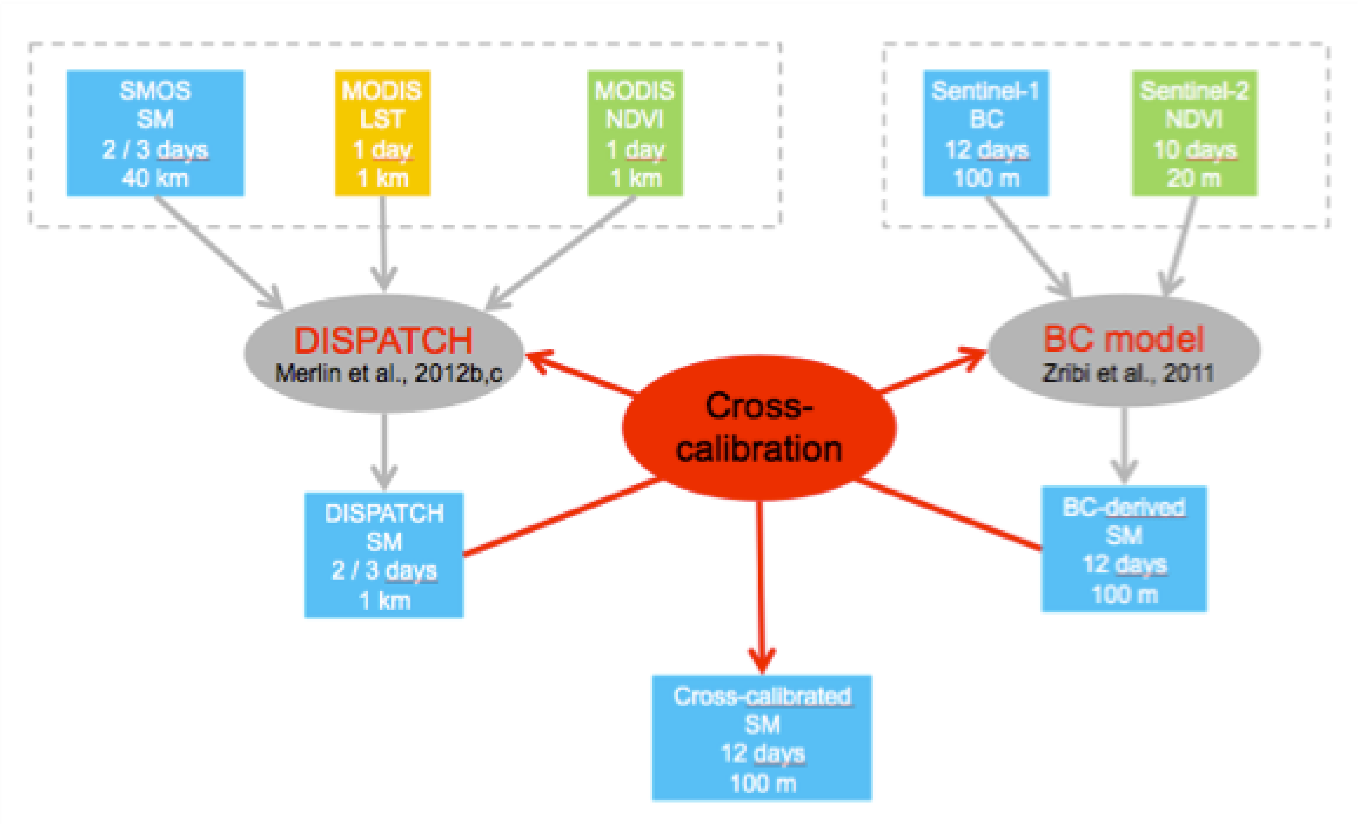
SMELLS Soil Moisture Stations

	SMELLS 1 km product		
	R	RMSE	bias
Akjoujt	0.78	0.020	0.016
FamHisn	0.67	0.020	-0.016
Yelimane	0.81	0.045	0.002
Tamanraset	0.45	0.154	-0.138

AMMA Soil Moisture Stations

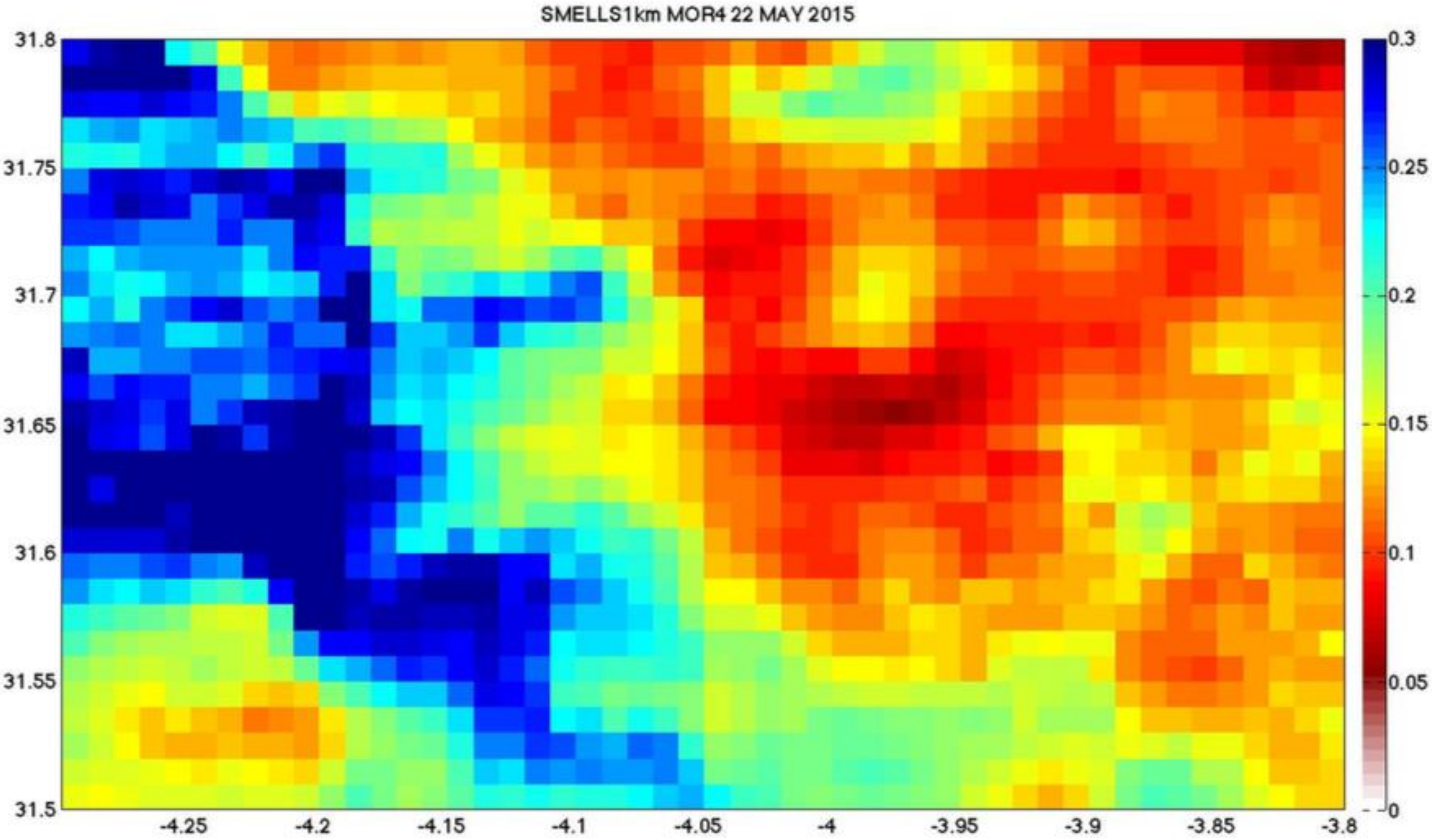
	SMELLS 1 km product		
	R	RMSE	bias
Agoufou	0.93	0.039	0.030
Tondi	0.82	0.046	0.030
Wankama	0.71	0.040	0.027
Bani	0.79	0.052	0.038

SMELLS 100m



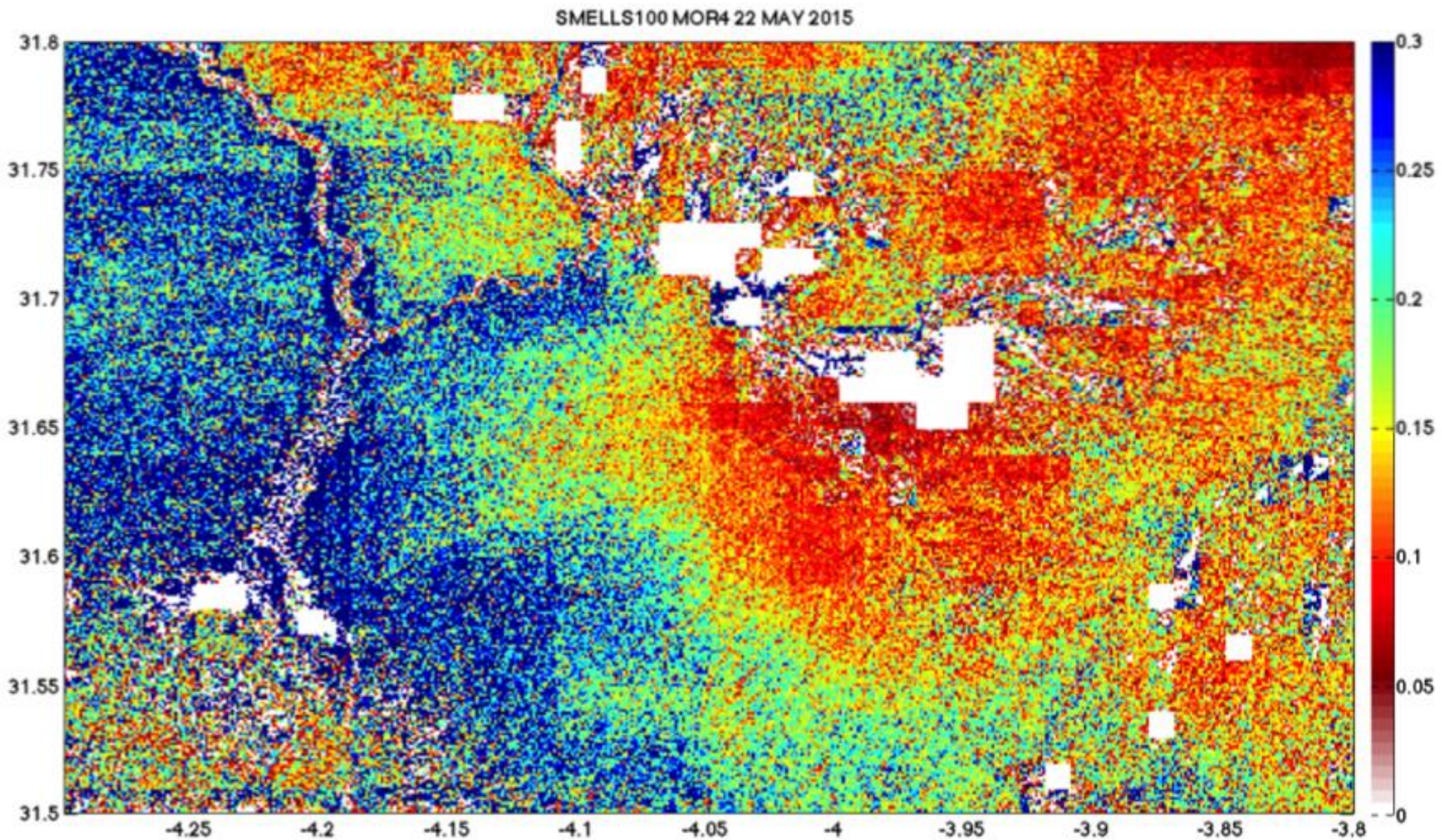
SMOS
SM
2 / 3 days
40 km
MODIS
LST
1 day
1 km
MODIS
NDVI
1 day
1 km
Sentinel-1
BC
12 days
100 m
Sentinel-2
NDVI
10 days
20 m
DISPATCH
Merlin et al., 2012b,c
Cross-calibration
BC model
Zribi et al., 2011
DISPATCH
SM
2 / 3 days
1 km
BC-derived
SM
12 days
100 m
Cross-calibrated
SM
12 days
100 m

SMELLS 1km



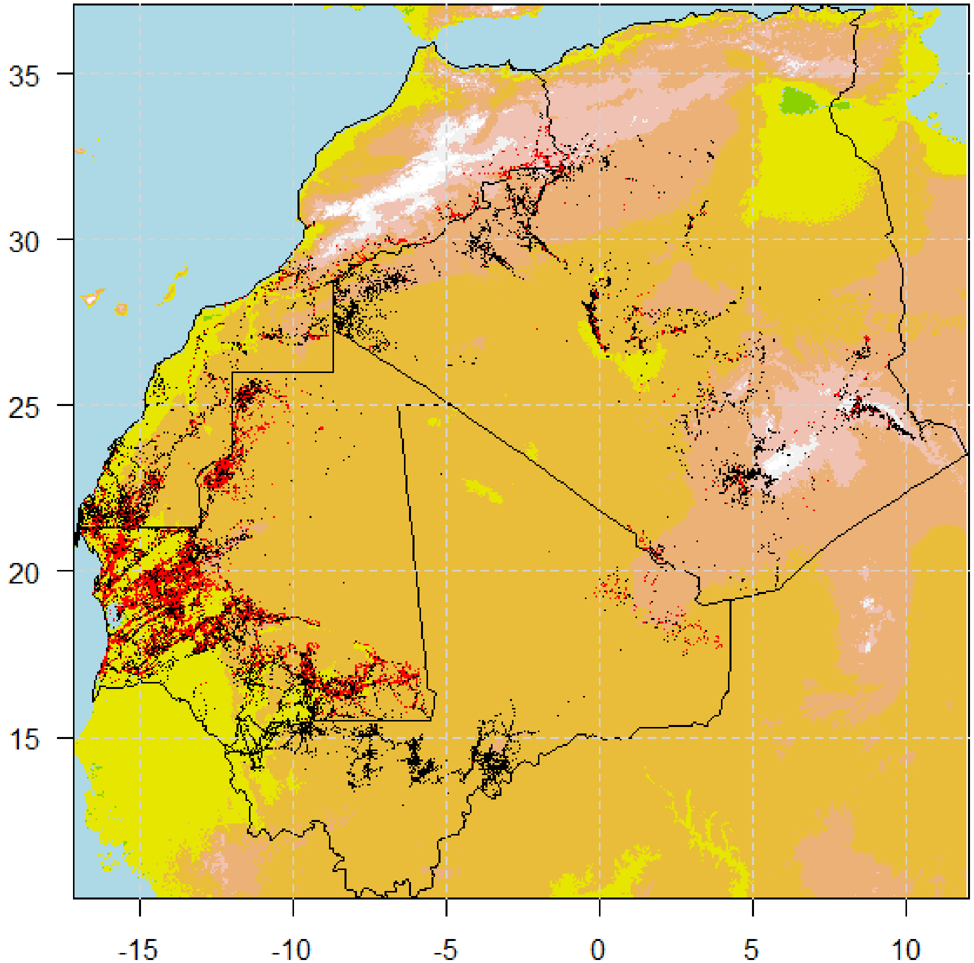
SMELLS1km MOR4 22 MAY 2015
31.8
31.75
31.7
31.65
31.6
31.55
31.5
-4.25
-4.2
-4.15
-4.1
-4.05
-4
-3.95
-3.9
-3.85
-3.8
0.3
0.25
0.2
0.15
0.1
0.05
0

SMELLS 100m


SMELLS100 MOR4 22 MAY 2015
31.8
31.75
31.7
31.65
31.6
31.55
31.5
-4.25
-4.2
-4.15
-4.1
-4.05
-4
-3.95
-3.9
-3.85
-3.8
0.3
0.25
0.2
0.15
0.1
0.05
0

SMELLS 100m

Validation with survey data



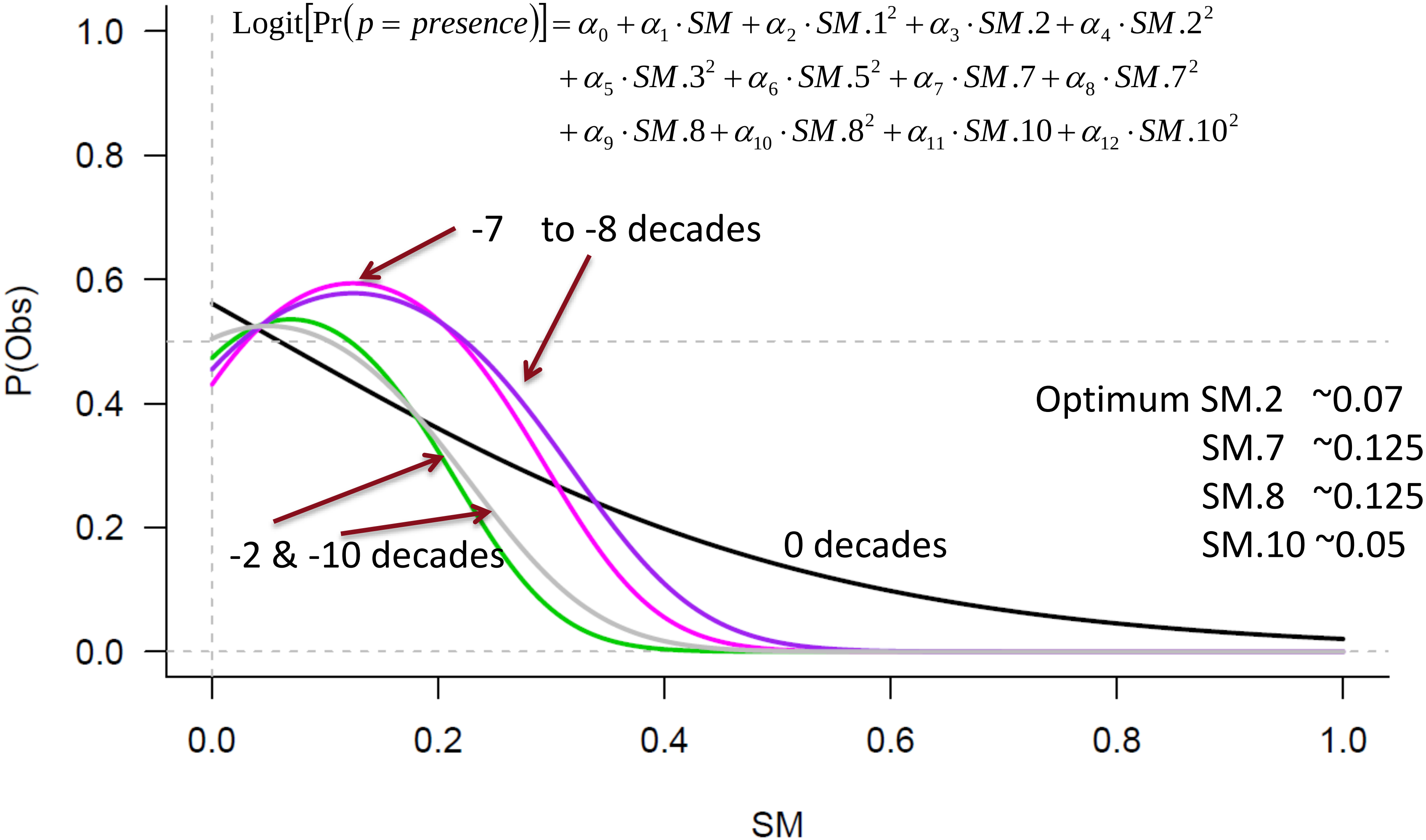
- 2010-2016
- 36700 survey points
- 34800 points with satellite data
- 32563 points after synthesis per km² and decade

6262 INPV → 17.1% of presence
2770 CNCLP → 4.2% of presence
19192 CNLA → 59.9% of presence
4339 CNLAA → 46.3% of presence

Validation with survey data

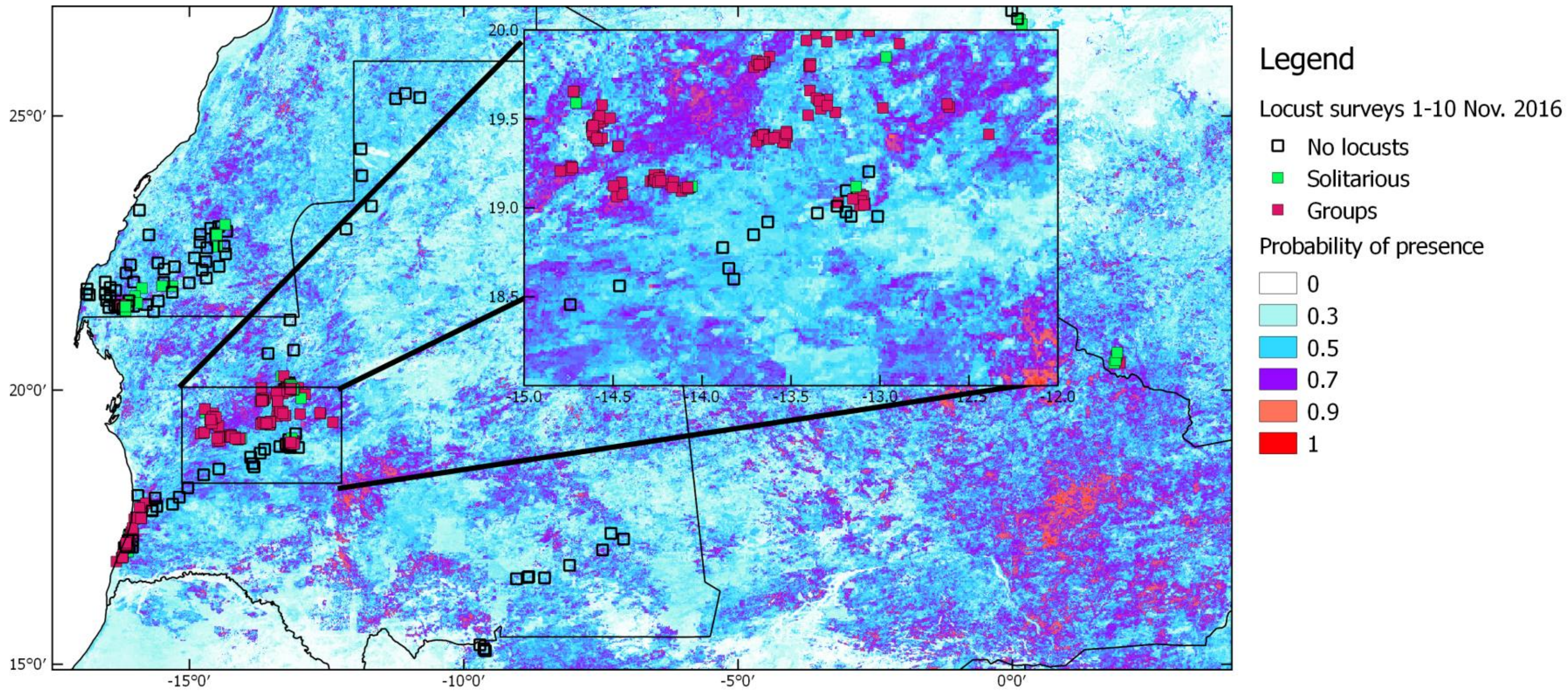
Analysis for SM 1km – which dynamics is best?

$$\begin{aligned}\mathrm{Logit}\left[\Pr\left(p = presence\right)\right] = {} & \alpha_0 + \alpha_1 \cdot SM + \alpha_2 \cdot SM.1^2 + \alpha_3 \cdot SM.2 + \alpha_4 \cdot SM.2^2 \\ & + \alpha_5 \cdot SM.3^2 + \alpha_6 \cdot SM.5^2 + \alpha_7 \cdot SM.7 + \alpha_8 \cdot SM.7^2 \\ & + \alpha_9 \cdot SM.8 + \alpha_{10} \cdot SM.8^2 + \alpha_{11} \cdot SM.10 + \alpha_{12} \cdot SM.10^2\end{aligned}$$



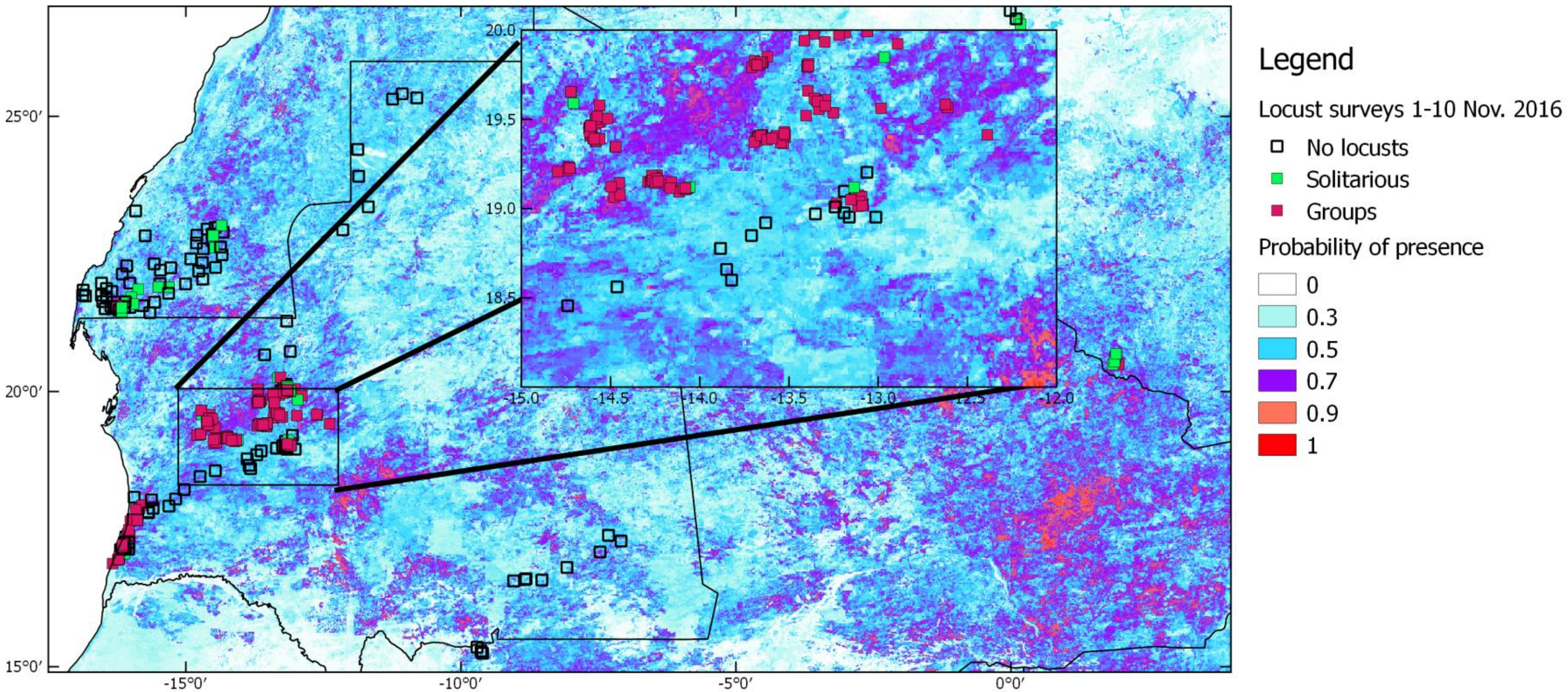
Building a prediction model

RandomForest model – only with SM adjusted on 2010-2015



Building a prediction model

November 2016 outbreak in Mauritania was concentrated on areas with Soil Moisture>0.1 seventy days before, as predicted by the analyses on 2010-2015 data



http://www.esa.int/Our_Activities/Observing_the_Earth/Satellites_forewarn_of_locust_plagues

Results

Long-term high-resolution Soil Moisture dataset produced for the entire users area of interest at 1km spatial resolution for the period 2010-2017 (http://smells.isardsat.com/data-portal/)

SMELLS 1km product has been thoroughly validated, its accuracy is amongst the best soil moisture products but at a better spatial resolution (1km against typically 40km)

Correlation values are good (R> 0.70) and RMSE around 0.04 m3m3 and decadal

SMELLS 100m has room for improvement, Dramatic increase of data acquisitions since October 2016 (linked to S1B launch)

Results

Soil Moisture can explain presence/ absence of Desert Locust with values significant to Desert Locust biology.

Soil Moisture allows to forecast locust presence 2–3 months ahead.

Current methodologies based on Vegetation Indices allow to predict presence only 1 month ahead.

Outlook

- The Soil Moisture products will be integrated into the national and global Desert Locust early warning systems in national locust centres and at FAO HQ, respectively.
- The Soil Moisture products should be extended to the entire Desert Locust recession area (0-40N/20W-80E).
- Integration of S3 LST in the SMELLS 1km algorithm
- Soil Moisture products at 100m and within root-zone to be investigated to provide further capacities of Desert Locust forecast.

Context

Agriculture is an important pressure on water resources Mediterranean countries agriculture uses 80% water available. The Mediterranean region is also one of the most sensitive areas to climate change

Sustainable water use is a growing concern worldwide. Increasing water use efficiency in agriculture has been identified as one of the key themes relating to water scarcity and drought.

Irrigation performance assessments at the field scale show a mismatch between irrigation requirements and the amount of irrigation water that is actually applied. **Optimize on-farm irrigation management**.

Irrigation and fertilizer management improvements **can help closing the crop yield gaps globally**.

Scientific Objectives

REC aims at develop an operational remote sensing algorithm dedicated to root zone soil moisture monitoring at the parcel scale.

REC will allow for the first time to:

1) to map root zone soil moisture on a daily basis at the field scale and
2) to quantitatively evaluate the different components of the water budget at the field scale from readily available remote sensing data.

These estimates will be integrated in an irrigation management system that will be used to trigger irrigation.

The approach is being implemented and validated in two sites in collaboration with their respective irrigation agencies:

- the modern irrigated area of Segarra-Garrigues in Lleida, Catalonia, Spain managed by ASG
- the irrigated perimeter of the Haouz Plain in the Tensift watershed, Morocco managed by the ORMVAH

Innovative EO: SSM

SSM
100 m/ 5-6 days

L-band Passive MW (40 km, 2/3 d)
+ Medium Resolution OT (1 km, 1 d)
+ High Resolution OT (100 m, 16 d)

SSM (1 km, 2/3 d)
SSM (100 m, 16 d) ✓

+ SAR S1 (20 m, 5/6 d)

SSM (100 m, 5/6 d)

Disaggregation of passive MW derived soil moisture with DISPATCH: current status and developments. *Vivien Stefan.*

Downscaling the SMOS soil moisture data at 1 km and 100 m resolution using MODIS and Landsat optical/thermal data. *Nitu Ojha.*

Disaggregation of SMOS soil moisture to 100 m resolution using MODIS optical/thermal and Sentinel-1 radar data: evaluation over a bare soil site in Morocco. *Omar Ali Eweys.*

Synergetic Use of Sentinel-1 and Sentinel-2 Data for Soil Moisture Mapping at 100 m Resolution. *Qi Gao.*

Soil moisture retrieval from a synergy between Sentinel-1 radar and Landsat-7/8 thermal data. *Abdelhakim Amazirh.*

Sensitivity of Sentinel-1 radar data to biophysical parameters over irrigated crops. *Soufiane Sersif.*

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Disaggregation of SMOS soil moisture to [illegible]on using MODIS optical/thermal and Sentinel-1 radar data: evaluation [illegible]il site in Morocco. *Omar Ali Eweys.*

On Going

Synergetic Use of Sentinel-1 [illegible]2 Data for Soil Moisture Mapping at 100 m Resolution. *Qi Gao.*

Soil moisture [illegible] a synergy between Sentinel-1 radar and Landsat-7/8 thermal data. [illegible]*kim Amazirh.*

Sensitivity of Sentinel-1 radar data to biophysical parameters over irrigated crops. *Soufiane Sersif.*

Task 2: Establish a list of the different products (L1 to L4) supported by L-Band measurements together with their accuracies and feasibility/ maturity (Science Readiness Level SRL). The products will also be evaluated in terms of ARL(application Readiness Level).

For each product, the following features are reported when available:

- Product accuracy in physical units
- Temporal and spatial resolution requirements
- Scientific Readiness Level (SRL)
- Application Readiness Level (ARL)
- L-band uniqueness / options

Science Readiness Level

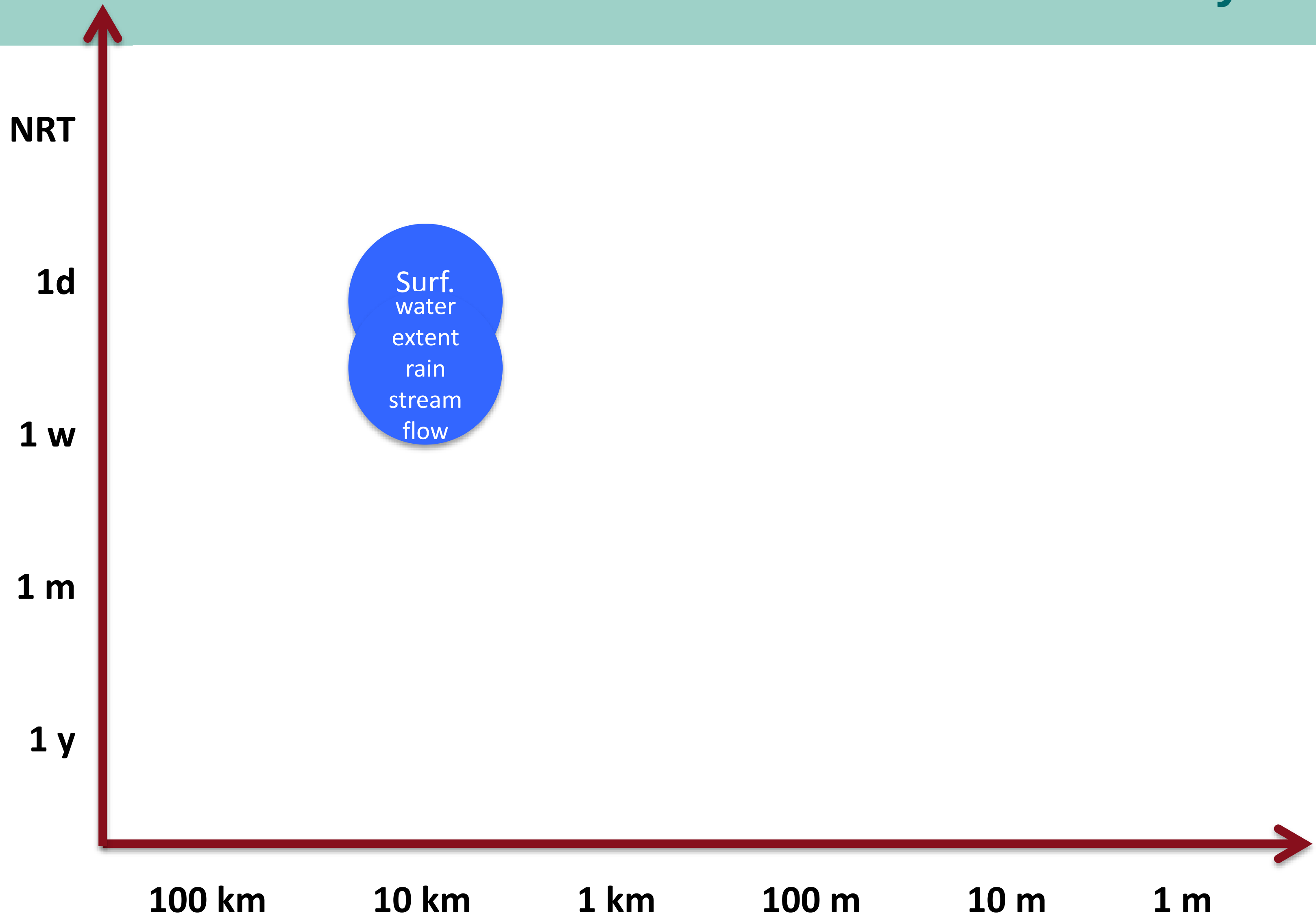
Phase F	9	Science Impact Quantification
Phase E2	8	Validated and Matured Science
Phase E1	7	Demonstrated Science
Phase B, C, D	6	Consolidated Science and Products
Phase A	5	End-to-End Performance Simulations
Phase 0	4	Proof of Concept
(Pre –) Phase 0	3	Scientific and Observation Requirements
Pre – Phase 0	2	Consolidation of Scientific Ideas
Pre – Phase 0	1	Initial Scientific Idea

European Space Agency

Application Readiness Level

Application Area	Required			SRL	ARL	Latency	Uniqueness
	Spatial	Temporal	Accuracy				
SSM	10 km	1d	0.020	9	8	NRT	
RZSM	10 km	1d		9	7	1d	
Inland Surface Water Extent	10 km	3d	2,5K	7	5	1w	
Enhanced Stream Flow	10 km	3d	1K	6	5	1w	
Enhanced Rainfall	10 km	3d	0.04	8	6	1d	

Hydrology


NRT
1d
1 w
1 m
1 y
Surf. water extent
rain
stream flow
100 km
10 km
1 km
100 m
10 m
1 m

Land: Carbon Cycle and Agriculture

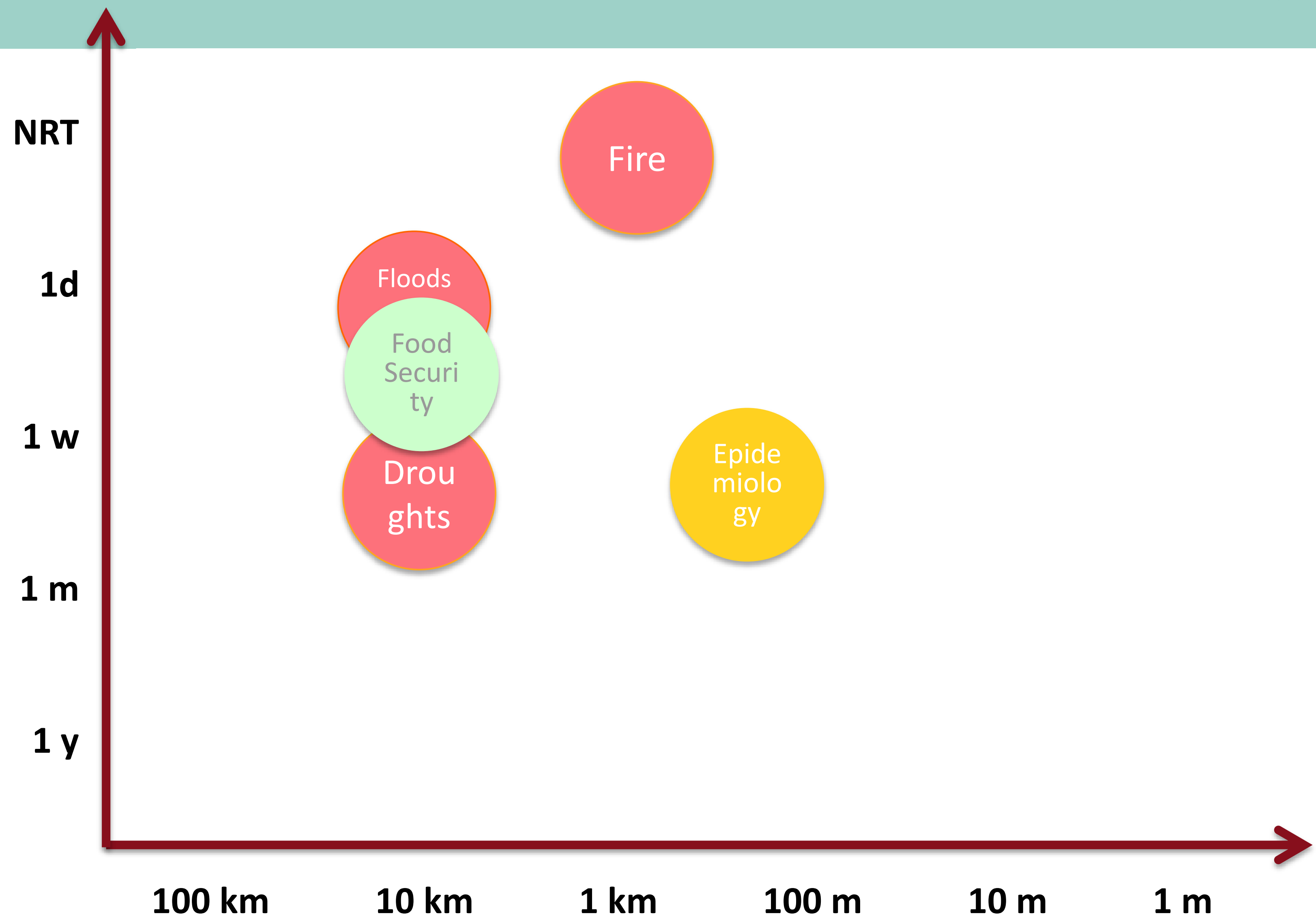
Application Area	Required			SRL	ARL	Latency	Uniqueness
	Spatial	Temporal	Accuracy				
Carbon cycle: tree biomass	25 km	1 m	80%	7	4	1 w	Active radar also useful
Large scale carbon exchange fluxes (L4) and phenology	100 km	1d	20%	5	6	3 m	Active radar also useful
Agriculture: Crop Yield	30 m	5d	20 %	8	4		O/T limited by clouds
Agriculture: Irrigation	30m	1d	0.04	8	5		O/T limited by clouds
Forestry: Yield	10m	2m	95%	7	6		

Agriculture /Carbon Cycle

Land: Hazards

Application Area	Required			SRL	ARL	Latency	Uniqueness
	Spatial	Temporal	Accuracy				
Flash Flood forecasting	10 km	1d	0.04	7	6	NRT	Need real SM measurements
Drought Early Warning	10 km	10d	0.04	4	4	24 h	Needs real SSM measurements
Fire risk assessment	1km	NRT	0.04	4	3	NRT	Needs real SM measurements
Food Security: Yield	10km	1d	0.04	6	4		
Desert Locust Management	100m	10 d	0.04	7	6	3 d	
Epidemiology: malaria, Vector Born Diseases	100m	10 d	0.04	2	2	3 d	

Land: Hazards



Application Area	Required			SRL	ARL	Latency	Uniqueness
	Spatial	Temporal	Accuracy				
Air-sea interaction/Climate change: SSS long term change (>10years)	5º	1y	0.005psu	4	3	6m	No/ in situ (Argo+ship)
Air-sea interaction: barrier layer and vertical compensated layers	0.5°	1w	0.1	4	3	NRT - Weeks	No/in situ (but most of them are deeper than 2m depth)
Air-sea interactions/climate variability: ENSO/IOD	1°	8d	0.2	7	6	1w	No/ in situ (Argo+ship)

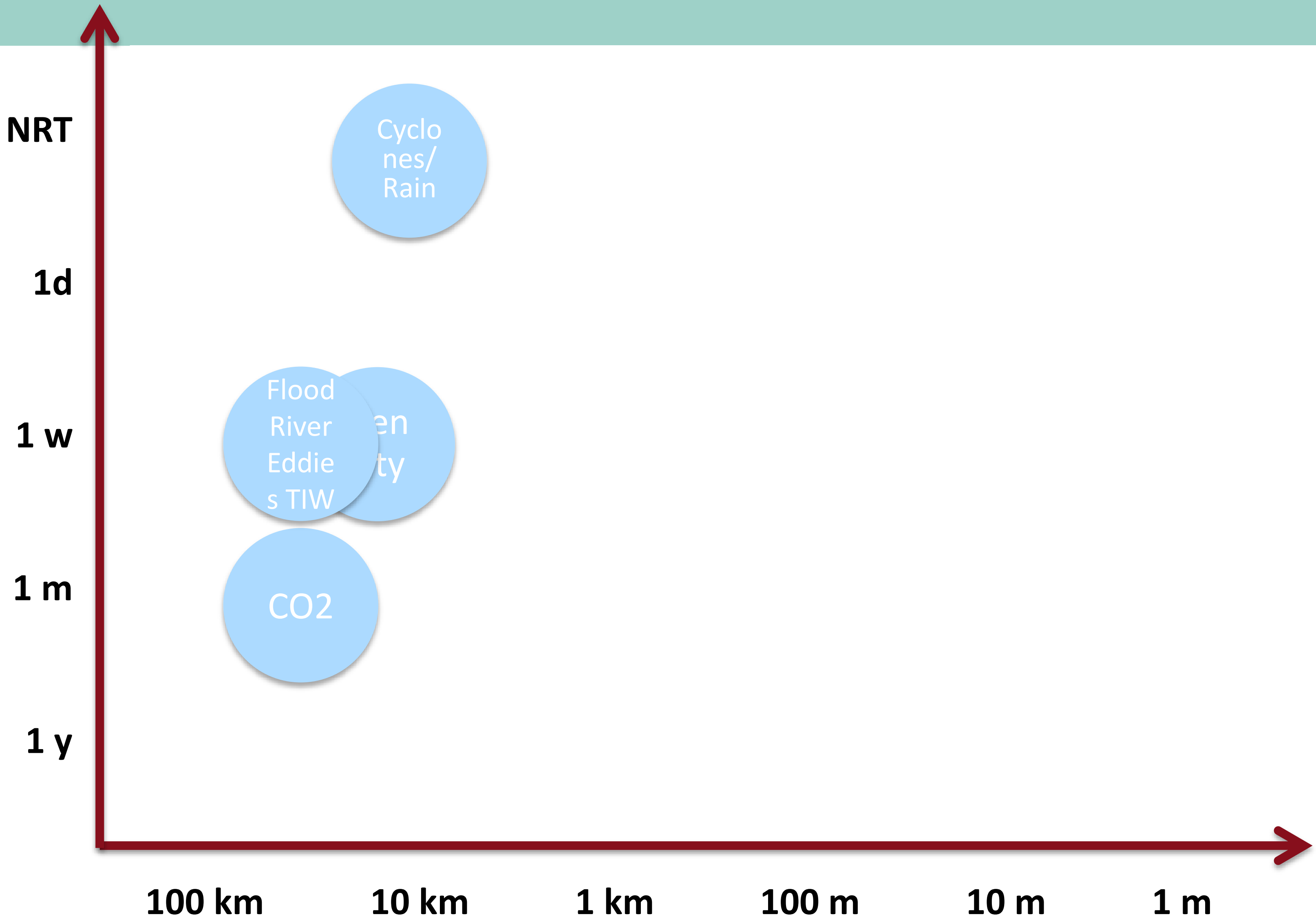
Open Ocean

Application Area	Required			SRL	ARL	Latency	Uniqueness
	Spatial	Temporal	Accuracy				
Ocean circulation: mesoscale/ eddy propagation	50km	1w	0.1	4	3	NRT	Yes
Ocean circulation: density compensation	.25°	8d	0.15	4	3		Yes
Ocean Circulation: TIW	50km	8d	0.1	4	3		Yes
Ocean circulation: AMOC	100km	1m	0.02	3	3		

Application Area	Required			SRL	ARL	Latency	Uniqueness
	Spatial	Temporal	Accuracy				
Freshwater Fluxes: River plumes	50km	8d	0.2	7	6		Yes
Freshwater Fluxes: Rain	10km	NRT	1	5	3	NRT	Yes
Freshwater Fluxes: Ice melting	50km	4d	0.5	1	1		
Carbon Cycle and biogeochemistry: air-sea CO2 fluxes	50km	1m	0.1	4	3	6m	Yes
Carbon Cycle and biogeochemistry: alkalinity	50km	1m	0.1	7	6	6m	No/ In situ (Argo)

Open Ocean

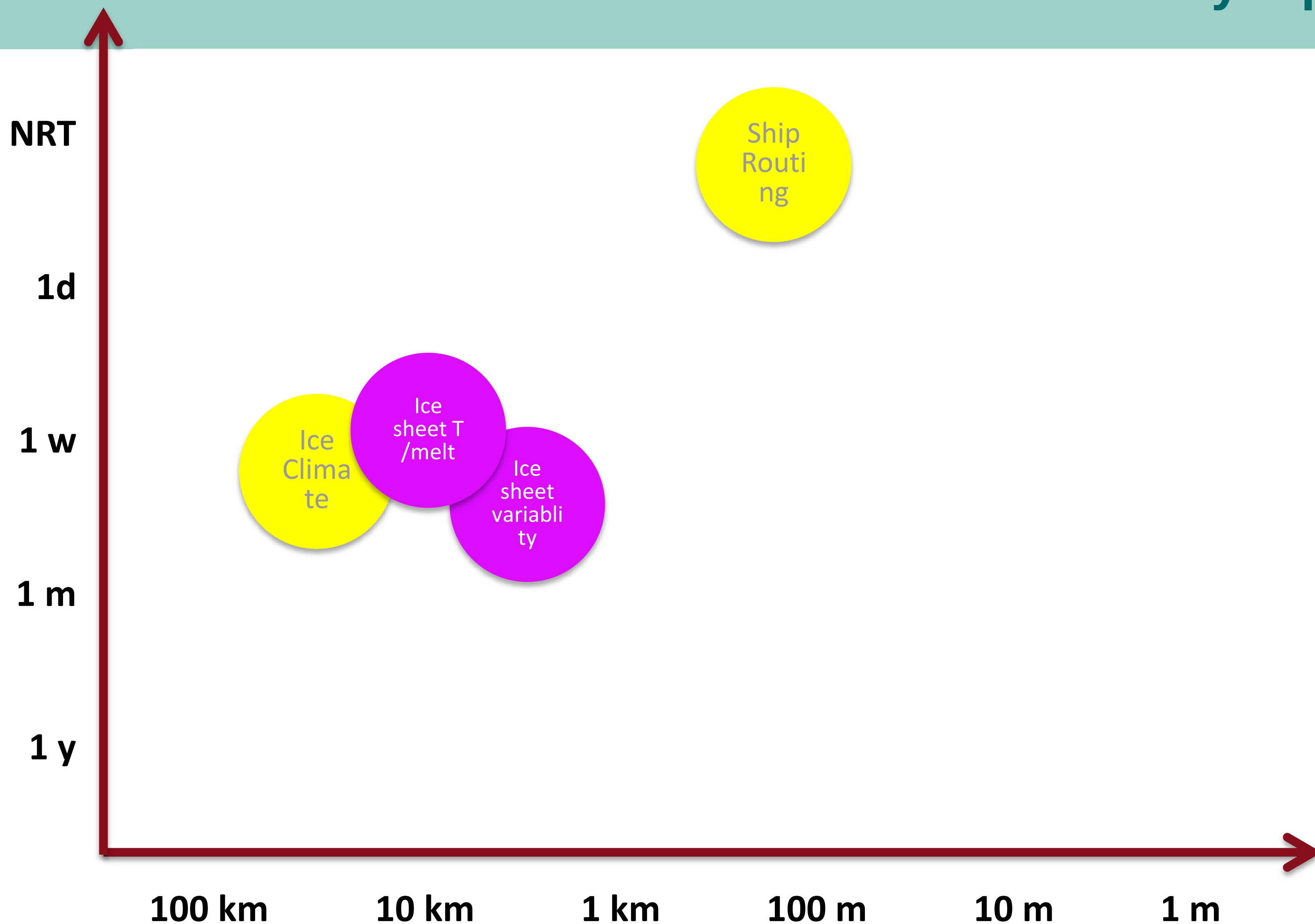
Application Area	Required			SRL	ARL	Latency	Uniqueness
	Spatial	Temporal	Accuracy				
Extreme events/Air-sea interactions: Cyclones	10km	<4h	5m/s	8	7	NRT	Yes
Extreme events: Flooding	50km	1w	1	7	6	6m	Yes


NRT
1d
1 w
1 m
1 y
Cyclo
nes/
Rain
en
ty
Flood
River
Eddie
s TIW
CO2
100 km
10 km
1 km
100 m
10 m
1 m

Cryosphere

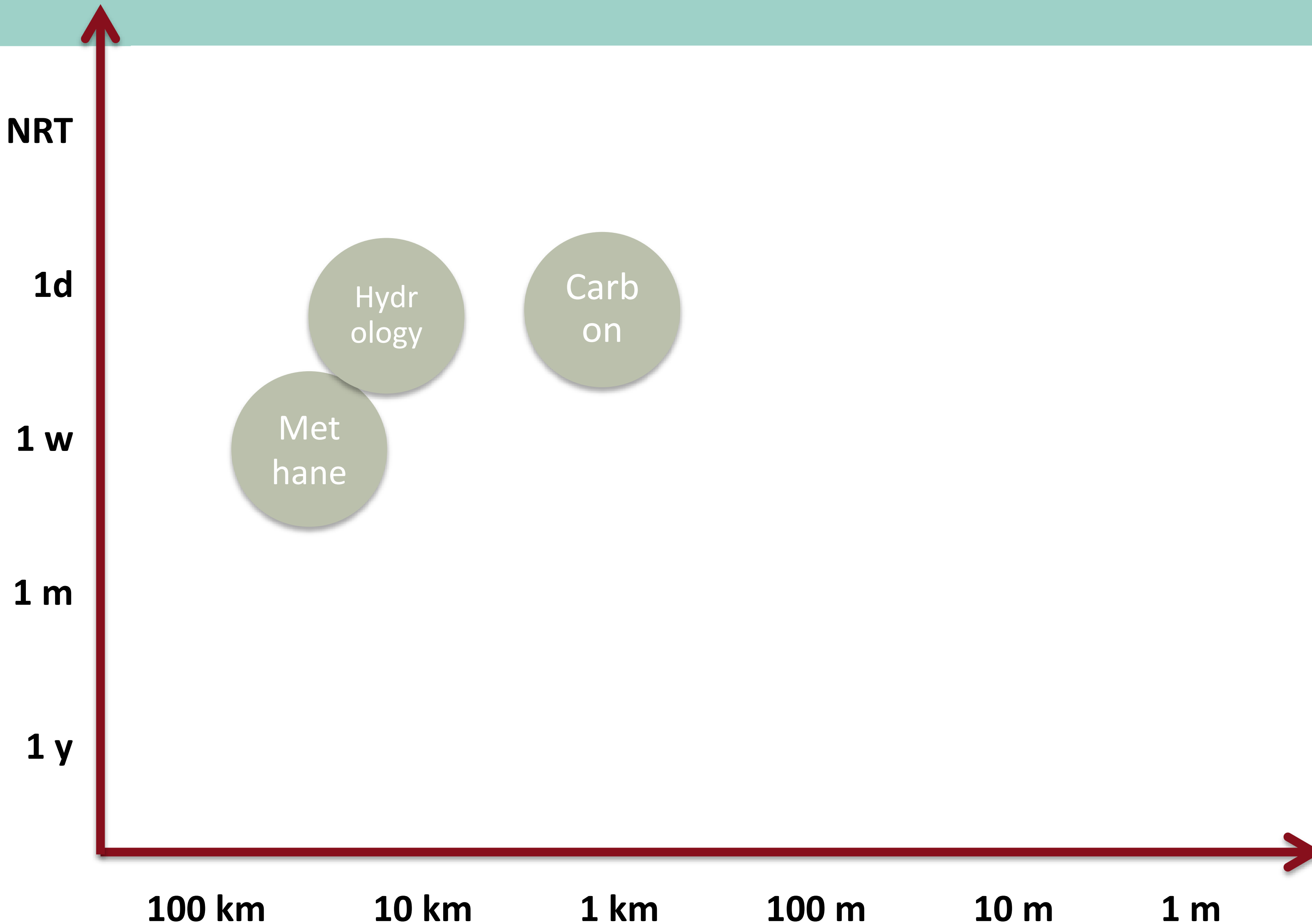
Application Area	Required Spatial	Required Temporal	Required Accuracy	SRL	ARL	Latency	Uniqueness
Sea ice and climate	25km	1w	5%	3	6	not critical	CryoSat2 / IceSat
Sea ice thickness and ship routing	100m	NRT	10%	4	3	1 hour	Airborne systems
Ice Sheets Temperature Profile	10 km	-	1 K	3	2		YES
Ice Sheets Surface Melting	10km	1 w	-	3	2	1 d	19 GHz
Ice Sheet Variability	5 km	10 d	0.04	2	1		Altimetry
Near-Surface properties				2	1		

Cryosphere


NRT
1d
1 w
1 m
1 y
Ship Routi ng
Ice Clima te
Ice sheet T /melt
Ice sheet variabli ty
100 km
10 km
1 km
100 m
10 m
1 m

Cryosphere: Soil freeze and thaw states

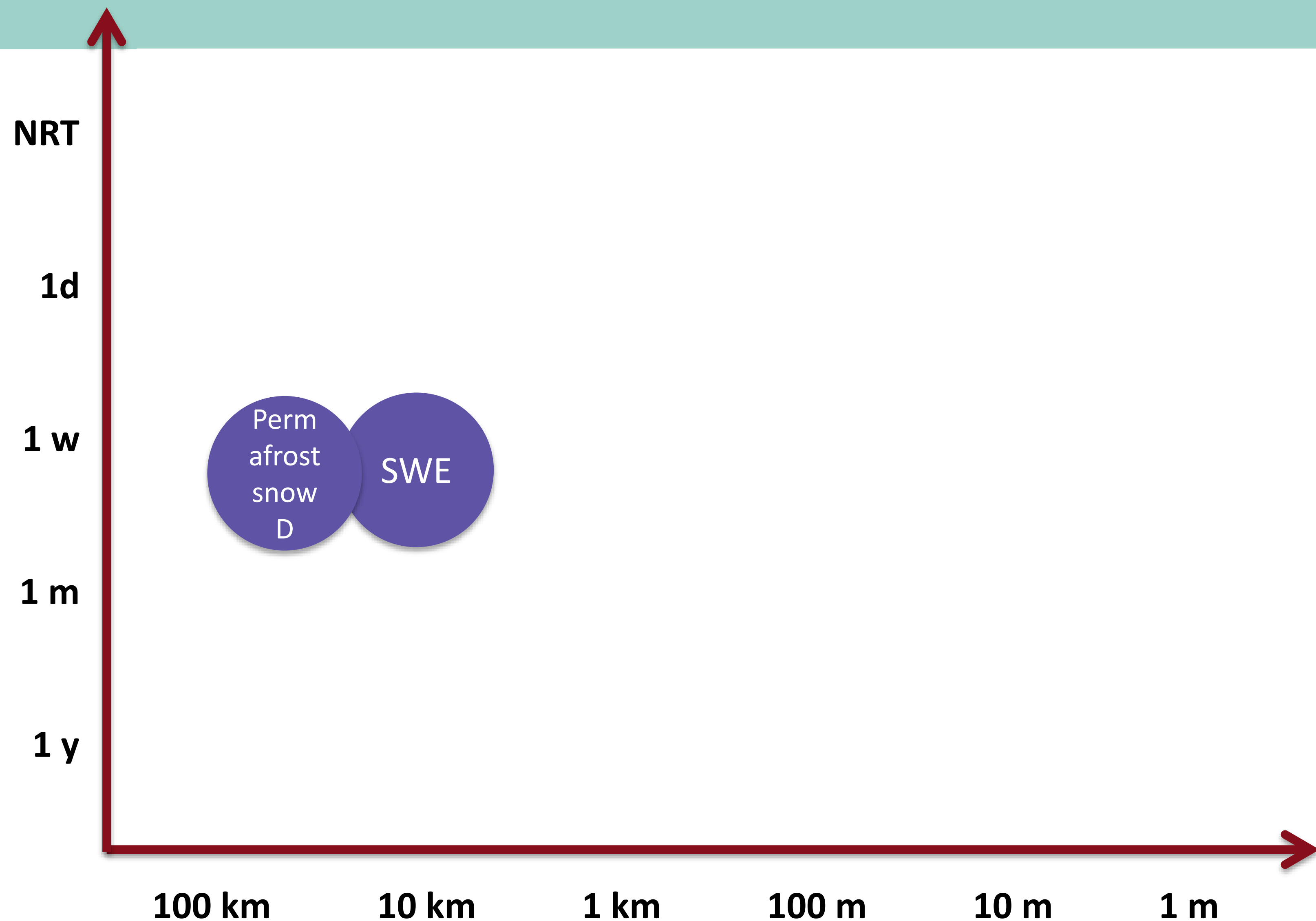
Application Area	Required			SRL	ARL	Latency	Uniqueness
	Spatial	Temporal	Accuracy				
F/T: inversion modelling (methane fluxes)	50 km	7d	1 day	7		6 m	Yes
F/T: process studies (carbon exchange)	1 km	1 day	1 day	7		7d	Yes
F/T: operational hydrology	10 km	1 d	1 d	7		1 d	Yes
Forest Trafficability						Daily	


NRT
1d
1 w
1 m
1 y
Hydr ology
Carb on
Met hane
100 km
10 km
1 km
100 m
10 m
1 m

Cryosphere: Snow and permafrost

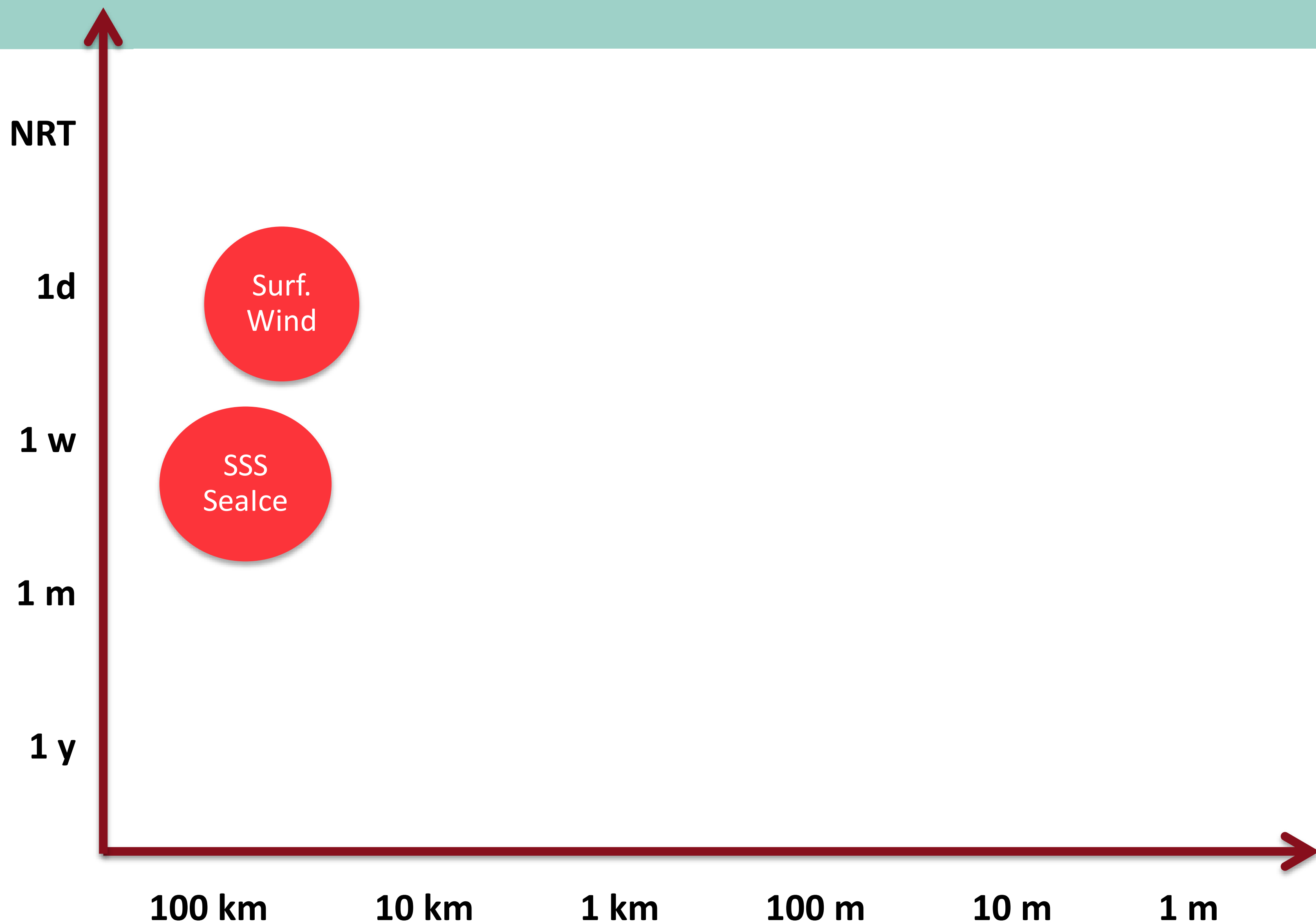
Application Area	Required			SRL	ARL	Latency	Uniqueness
	Spatial	Temporal	Accuracy				
Snow density: inversion modelling (methane fluxes)	50 km	1w	50 kg/m^3	4 -5			Yes
Snow density: support of hemispheric SWE retrieval	10 km	1 w	50 kg/m^3	4 -5			Yes
Permafrost: (active layer dynamics) for inversion modelling (methane fluxes)	50 km	1 w					Yes

Snow Permafrost



NWP

Application Area	Required			SRL	ARL	Latency	Uniqueness
	Spatial	Temporal	Accuracy				
NWP; soil moisture	10km	1d	0.04	9	9	3h	
Seasonal Prediction	15km	1d	0.04	9	9		
NWP; sea ice thickness	100km	14d	1m		5	3h	Unique for thin ice
NWP: SSS	100km	10d	0.2psu		1	3h	Potential for validation and assimilation
NWP; atmosphere/surface winds	50km	1d	10%		4	3h	Potential High wind speed


NRT
1d
1 w
1 m
1 y
Surf.
Wind
SSS
SeaIce
100 km
10 km
1 km
100 m
10 m
1 m

All


NRT
1d
1 w
1 m
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Rain
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Ship
Routi
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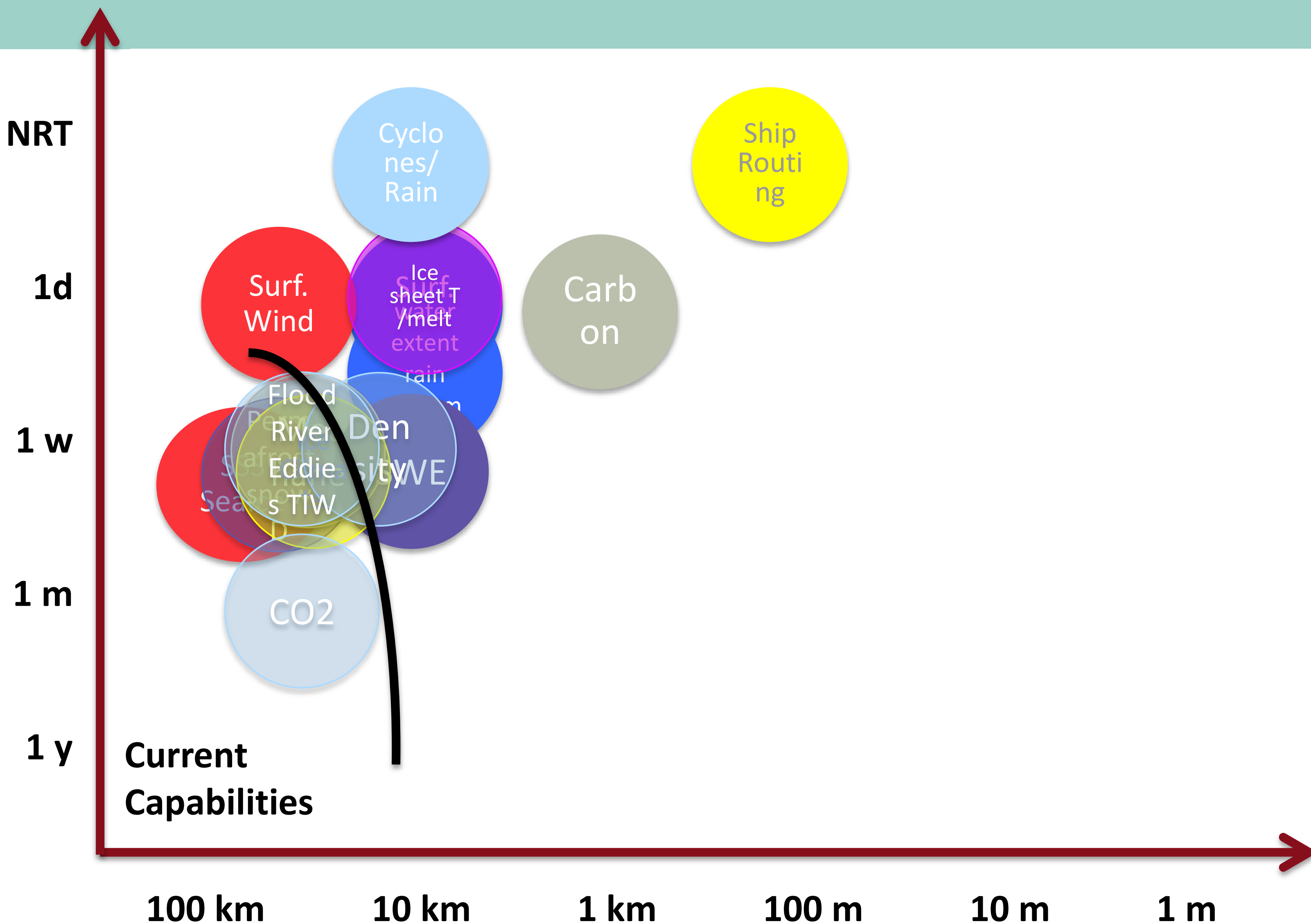
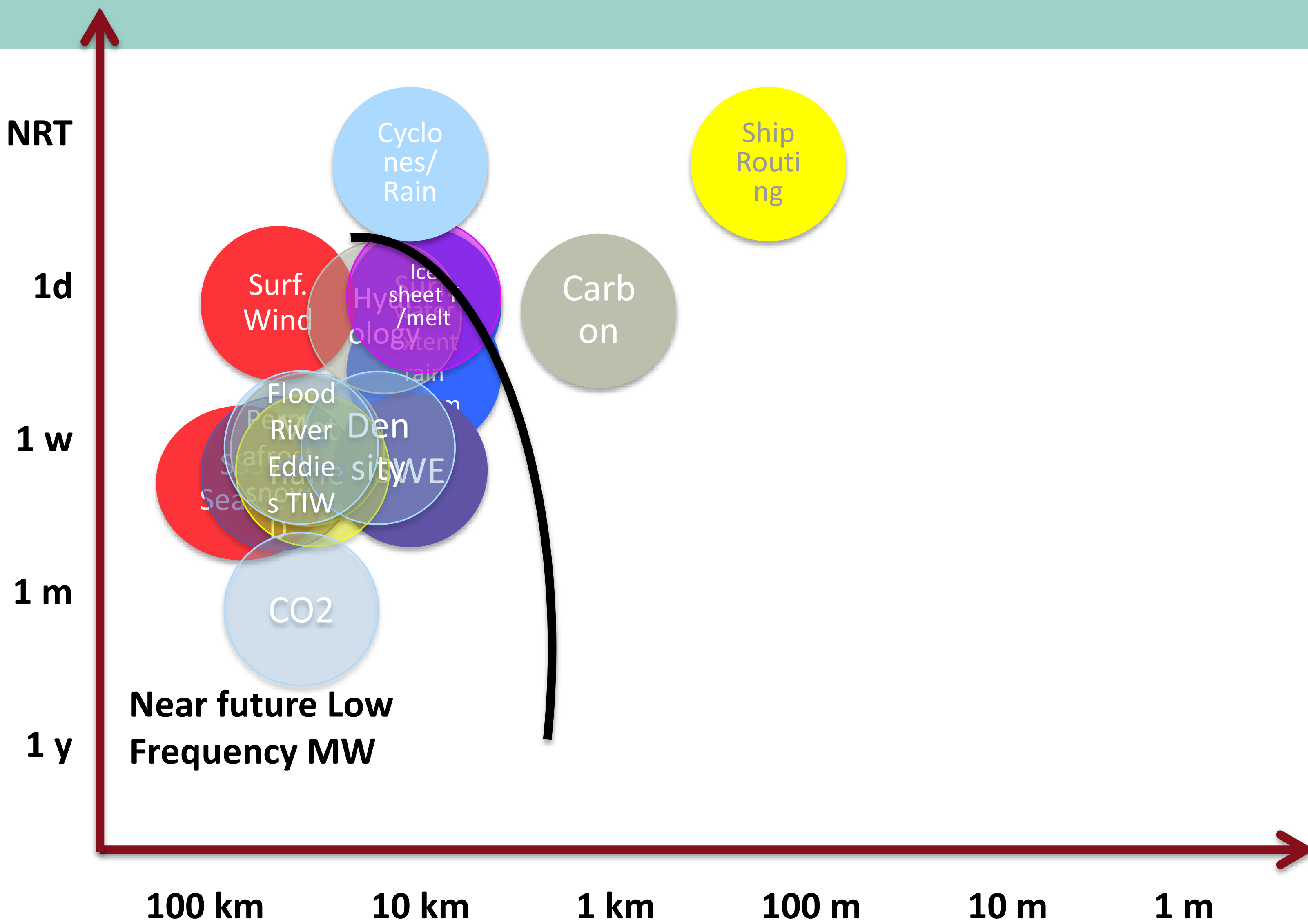
CO2
100 km
10 km
1 km
100 m
10 m
1 m

L-band Unique




NRT
1d
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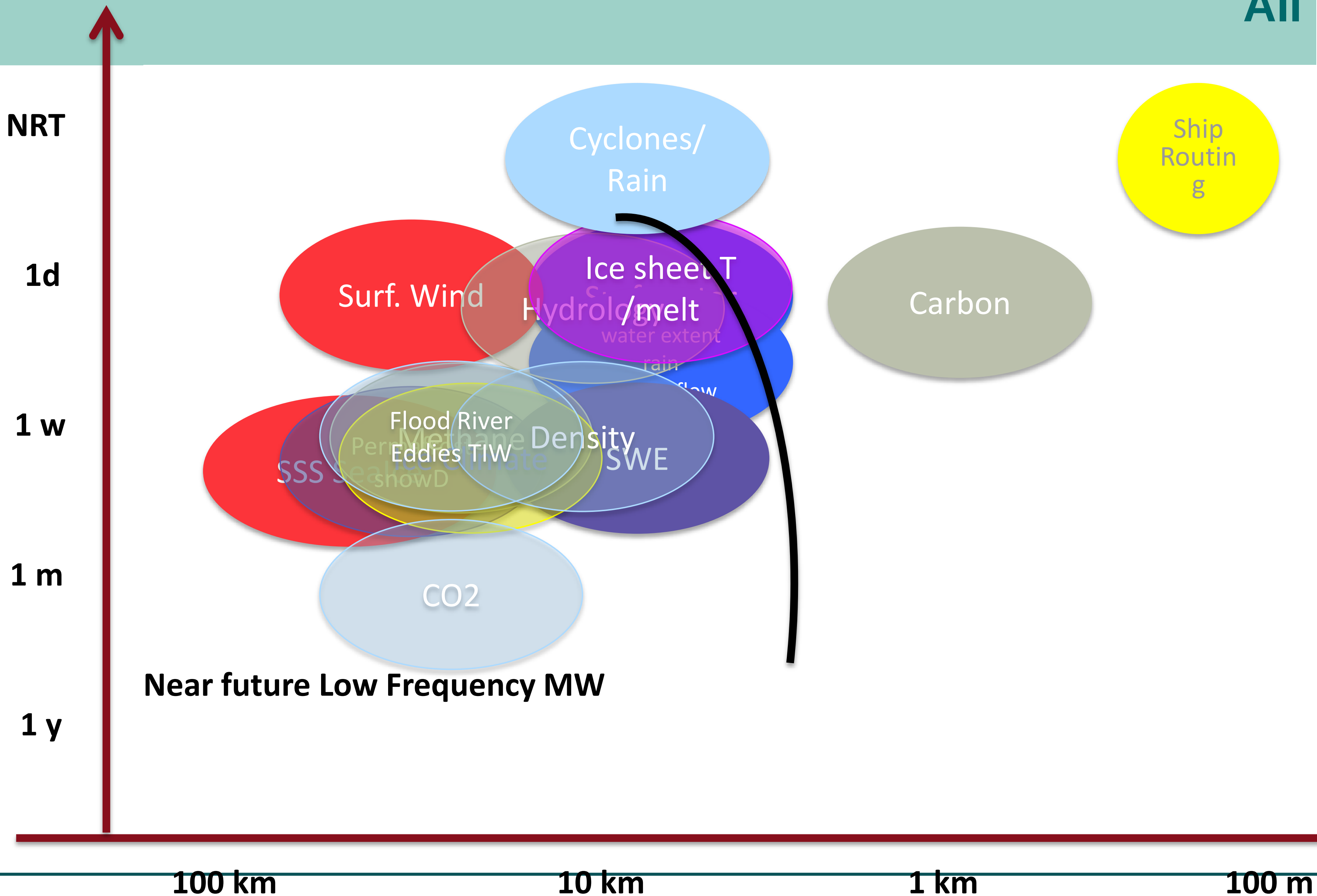
Cyclo nes/ Rain
Ship Routi ng
Surf. Wind
Ice sheet /melt
Carb on
Flood
River
Eddie s TIW
Den sity
CO2
Near future Low Frequency MW
100 km
10 km
1 km
100 m
10 m
1 m

All


NRT
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Cyclones/
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Carbon
Flood River
Eddies TIW
Density
SWE
SSS
snowD
CO2
Near future Low Frequency MW
100 km
10 km
1 km
100 m

Conclusions and Further Work

- Large number of unique applications based on low frequency MW (most need L-band)
- Required T/S/A technologically feasible for a large number of unique applications

The outcome is two fold:

- Produce a white paper summarizing the findings. This document is a living one regularly updated and complemented. To be the basic reference document describing where L band radiometry stands.

- Build up a working group of international stature that consolidates the requirements.

- -> you are welcome to participate! send an email:

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