ACCRA : A Study on Future Microwave Radiometers for Atmospheric Correction of Radar Altimeters on Coastal Regions

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Context

Altimeter performances in terms of spatial resolution rapidly improve

- LRM, Ku-band ~ 10 km (Jason's)
- LRM, Ka-band ~ 6 km (AltiKa)
- SAR mode (Cryosat, Sentinel-3) < 1 km
- SWOT (interferometry) < 1 km

Context

Meanwhile, the progresses on Microwave Radiometers spatial resolutions are slow:

- Jason's ~ 35 km (18.7 GHz, 23.8 GHz, 34 GHz)
- Envisat ~ 30 km (23.8 GHz, 36.5 GHz)
- Sentinel-3 ~ 25 km (23.8 GHz, 36.5 GHz)
- AltiKa ~ 10 km (23.8 GHz, 37 GHz)

Context

Meanwhile, the progresses on Microwave Radiometers spatial resolutions are slow:

➔this is clearly a limit for

coastal applications (land contamination)

hydrological applications

high-resolution SSH (convective cells)

Context

The ACCRA study (12 months, ended October 2016), fully supported by ESTEC, gathers experts in both hardware and retrieval fields and is based on the following credo :

The solutions to improve the spatial resolution rely ***both*** *on* ***a smart design***
and ***dedicated retrieval methods****.*

Objectives

- The objective of this activity is **to elaborate a novel MWR instrument** design at preliminary design level, aimed primarily for future operational altimetry missions such as next Generation Sentinel-3 and Jason-CS.

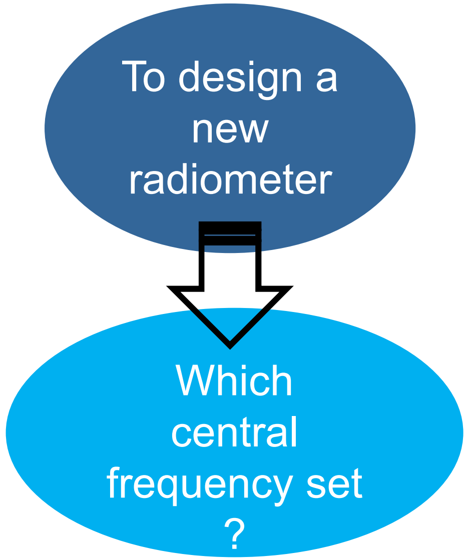
Objectives

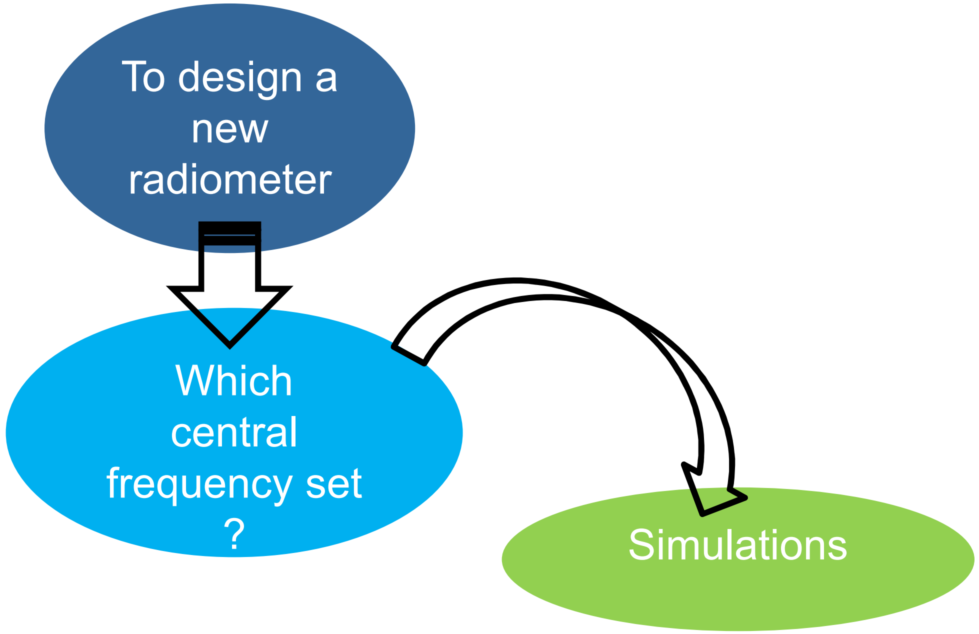
- The instrument shall comprise of
  - Two/three classical observation channels (Jason's)
  - A set of high frequency channels with higher spatial resolution for resolving coastal and inland waters.
  - HF channels shall enable retrievals over sea ice and ice-sheets.
- A compact instrument, not significantly exceeding the size of the current MWR's is desirable

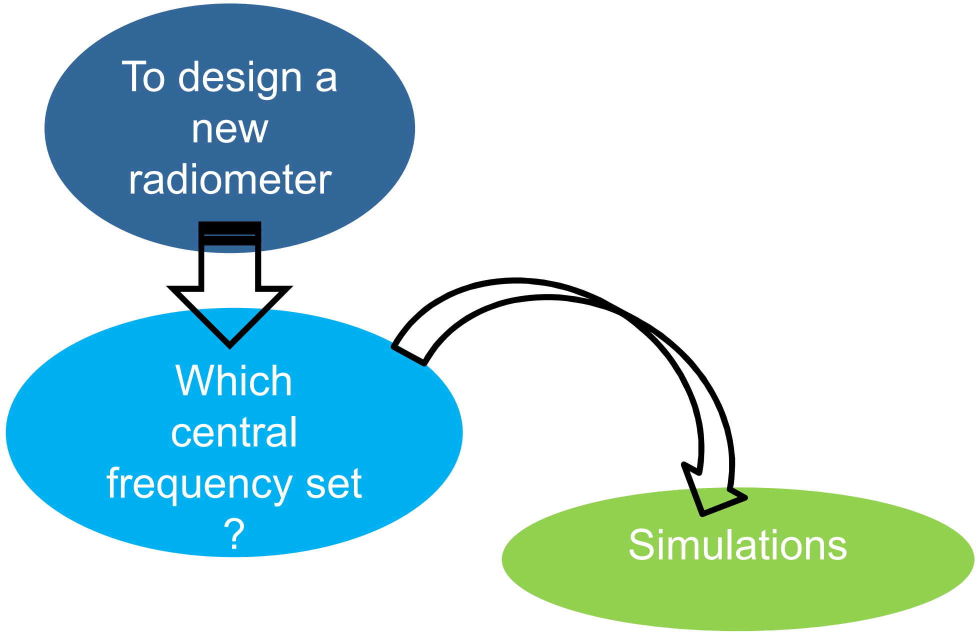
Objectives

- A dedicated retrieval algorithm of the wet tropospheric correction (accounting for the range delay due to the water vapour)
- To get the best of the HF channels over Ocean, Coastal regions, Land and Ice surfaces

To design a new radiometer


To design a new radiometer
Which central frequency set ?


To design a new radiometer
Which central frequency set ?
Simulations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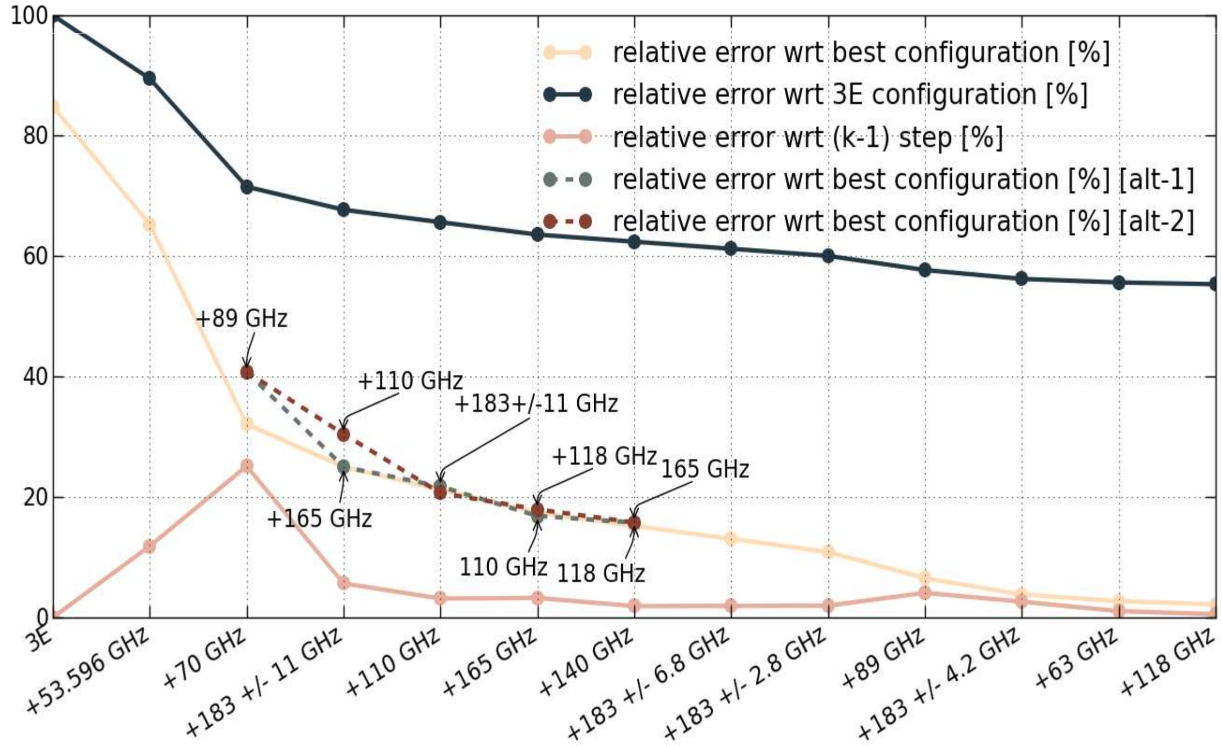
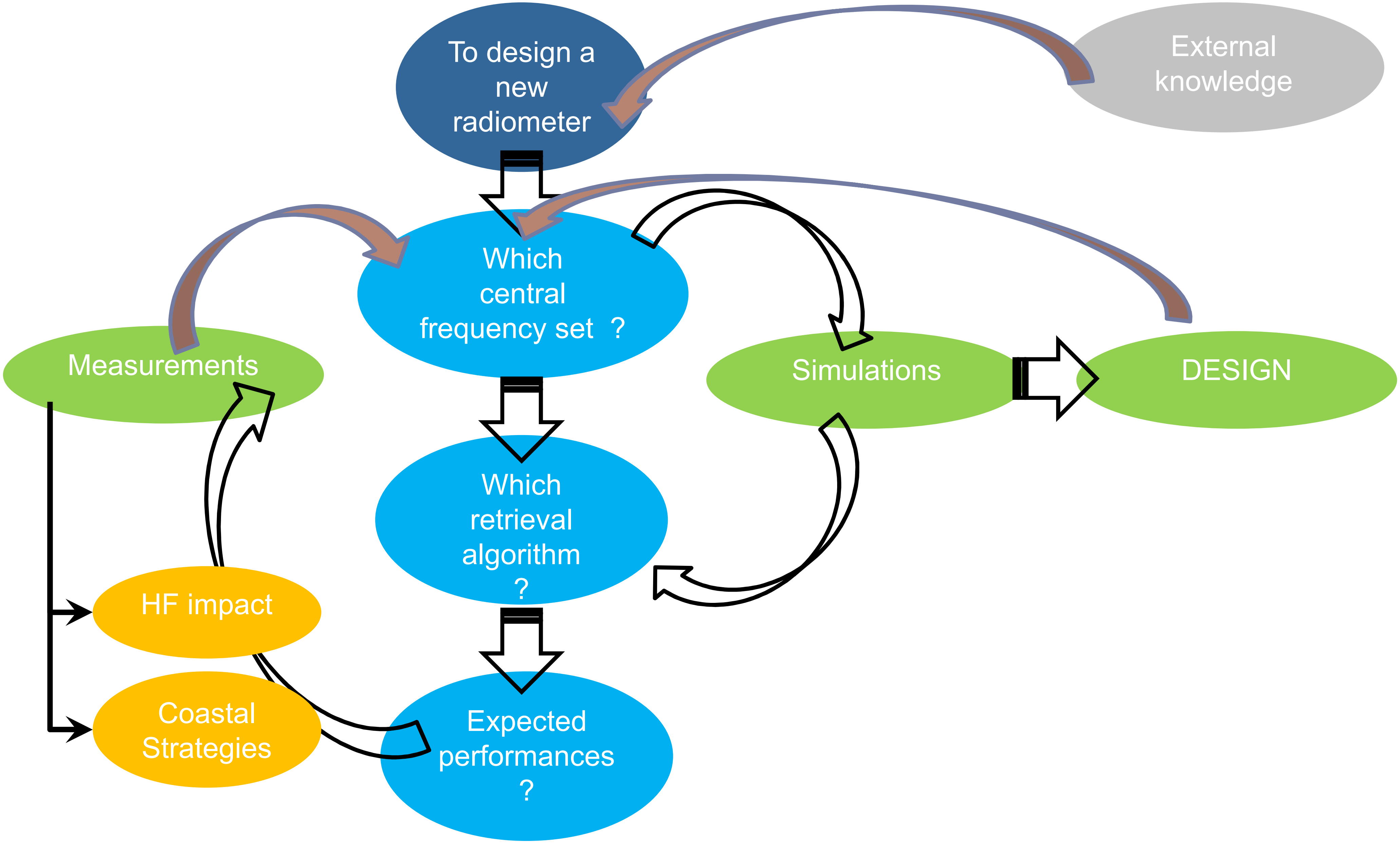

relative error wrt best configuration [%]
relative error wrt 3E configuration [%]
relative error wrt (k-1) step [%]
relative error wrt best configuration [%] [alt-1]
relative error wrt best configuration [%] [alt-2]
+89 GHz
+110 GHz
+183+/-11 GHz
+118 GHz
165 GHz
+165 GHz
110 GHz
118 GHz
3E
+53.596 GHz
+70 GHz
+183 +/- 11 GHz
+110 GHz
+165 GHz
+140 GHz
+183 +/- 6.8 GHz
+183 +/- 2.8 GHz
+89 GHz
+183 +/- 4.2 GHz
+63 GHz
+118 GHz



To design a new radiometer
External knowledge
Which central frequency set ?
Measurements
Simulations
DESIGN
Which retrieval algorithm ?
HF impact
Coastal Strategies
Expected performances ?

Task 1: selection of HF channels

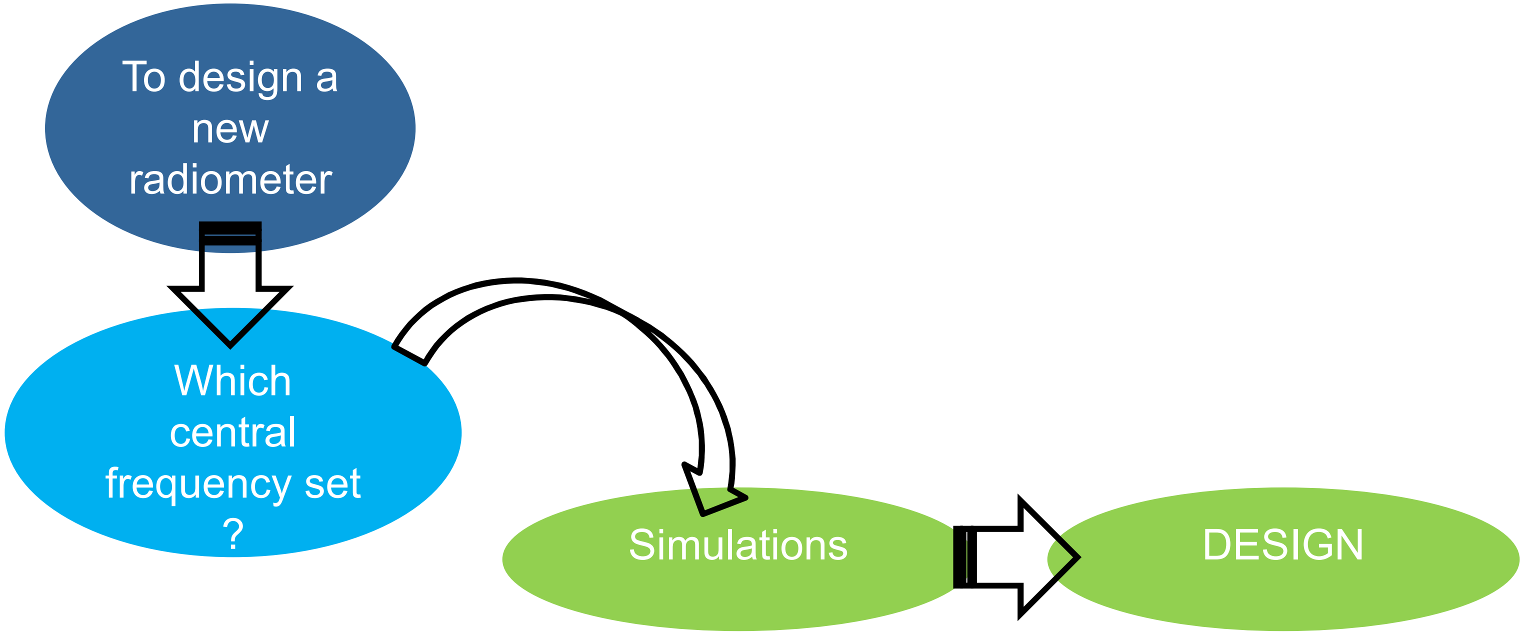
- 9 channels selected considering physical constraints: classical LF (18/23/36), surface emissivity (50.3/89), atm. temperature (54/118), window channels (110, 165), HF WV absorption line (183)

Channel	Central Frequency	DDR [MHz]	Sensitivity NeDT [K]	Spatial Resolution
MWR-1	18.7	200	<0.15 K	<15 km / < 25 km
MWR-2	23.8	400	<0.15 K	<15 km / < 25 km
MWR-3	36.5	200	<0.15 K	<15 km / < 25 km
MWR-4	50.3	400	<0.20 K	<10 km / < 15 km
MWR-5	53.596	400	<0.20 K	<10 km / < 15 km
MWR-6	89	3000	<0.20 K	<5 km / < 10 km
MWR-7	110.65	400	<0.25 K	<5 km / < 10 km
MWR-8	118	2x400	<0.25 K	<5 km / < 10 km
MWR-9	165	2x1350	<0.30 K	<5 km / < 10 km
MWR-10	183.31-11	2000	<0.30 K	<5 km / < 10 km

Task 1: selection of HF channels

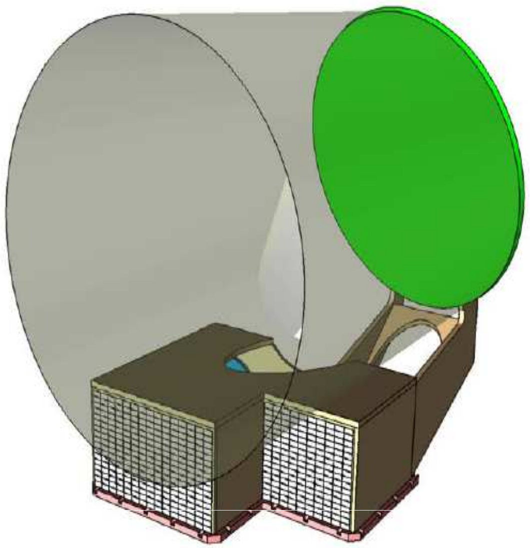
- 6 channels recommended by ESTEC considering cost/complexity constraints

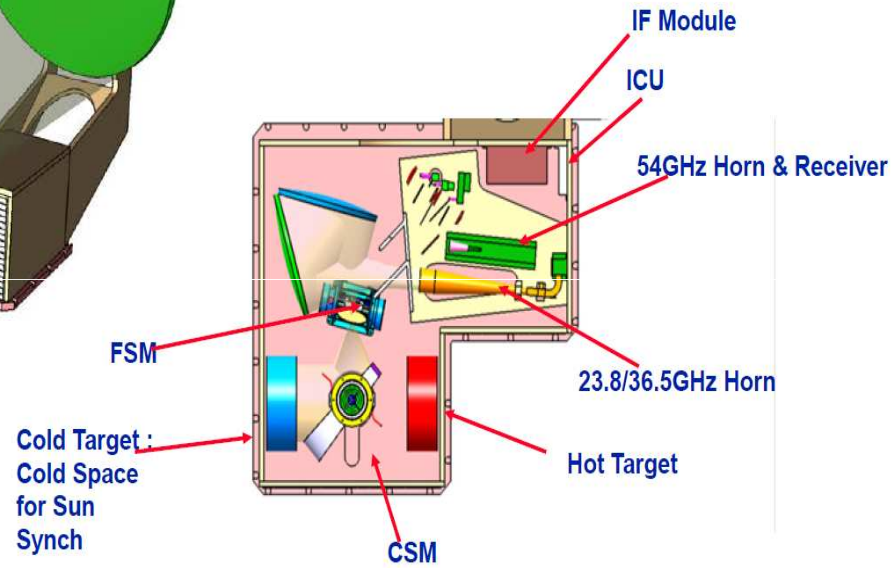
Channel	Central Frequency	DDR [MHz]	Sensitivity NeDT [K]	Spatial Resolution
MWR-1	23.8	400	<0.15 K	<15 km / < 25 km
MWR-2	36.5	200	<0.15 K	<15 km / < 25 km
MWR-3	50.3	400	<0.20 K	<10 km / < 15 km
MWR-4	53.596	400	<0.20 K	<10 km / < 15 km
MWR-5	89	3000	<0.20 K	<5 km / < 10 km
MWR-6	183.31-11	2000	<0.30 K	<5 km / < 10 km


To design a new radiometer
Which central frequency set ?
Simulations
DESIGN

Task 2: Instrument Design: configuration

- The overall volumetric dimensions for a 1.1m antenna aperture are :
  - Height : 1593mm
  - Width : 1421mm
  - Depth: 1570mm
- The dimensions of the interface to the platform are:
  - Width : 1085mm
  - Depth: 882mm



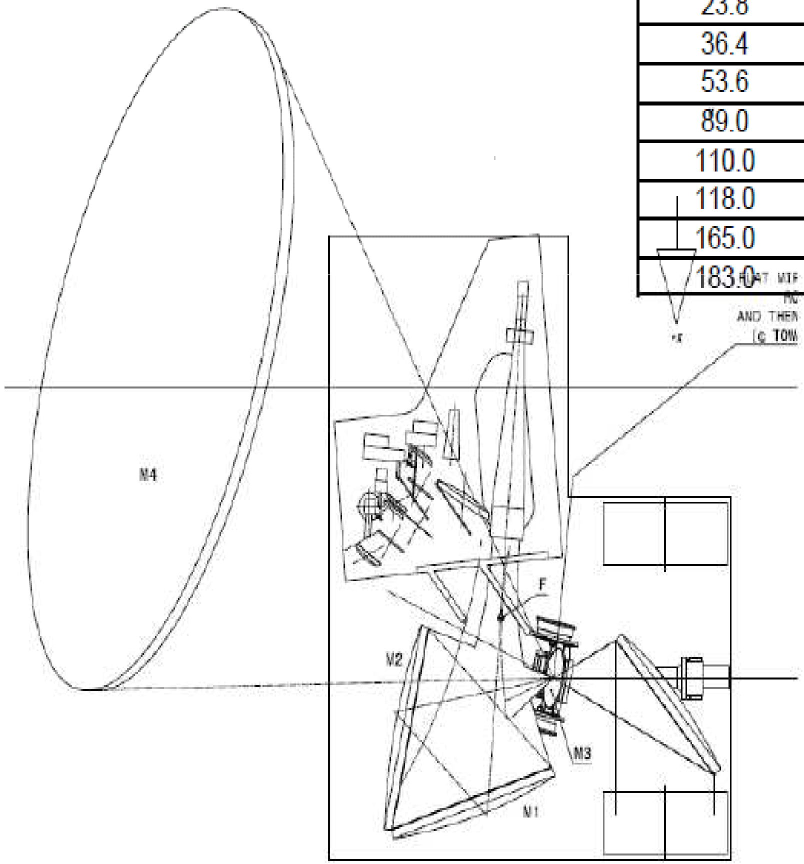


- Configuration does not currently illustrate a thermal shield for the primary reflector but expect this to be beneficial for at least the non sun synchronous orbit, possibly both orbits, as MWI has concluded. Also know from MWI that such a shield is also a mass efficient solution to the primary structural support.

Task 2: Instrument Design: system performances

Spatial Performance:

Frequency (GHz)	HPBW (min)	HPBW (max)	HPBW (mean)	BE (Co) %	BE (Xp) %	BE (total) %	FBE %	Remark
18.7	1.13	1.16	1.15*	95.2	0.4	95.6	96.0	>HPBW Spec
23.8	1.03	1.04	1.04	96.1	0.3	96.4	97.6	
36.4	1.01	1.02	1.02	98.55	0.25	98.8	99.0	
53.6	0.62	0.62	0.62	98.55	0.25	98.8	99.0	
89.0	0.32	0.34	0.33	98.15	0.25	98.4	98.7	
110.0	0.32	0.32	0.32	99.03	0.17	99.2	99.6	
118.0	0.34	0.34	0.34	99.15	0.15	99.3	99.6	
165.0	0.34	0.34	0.34	99.67	0.13	99.8	99.8	
183.0	0.34	0.35	0.35	99.77	0.13	99.9	99.9	



Antenna subsystem constrained
by high requirements on spatial resolution
and directivity to minimize side-lobes effect

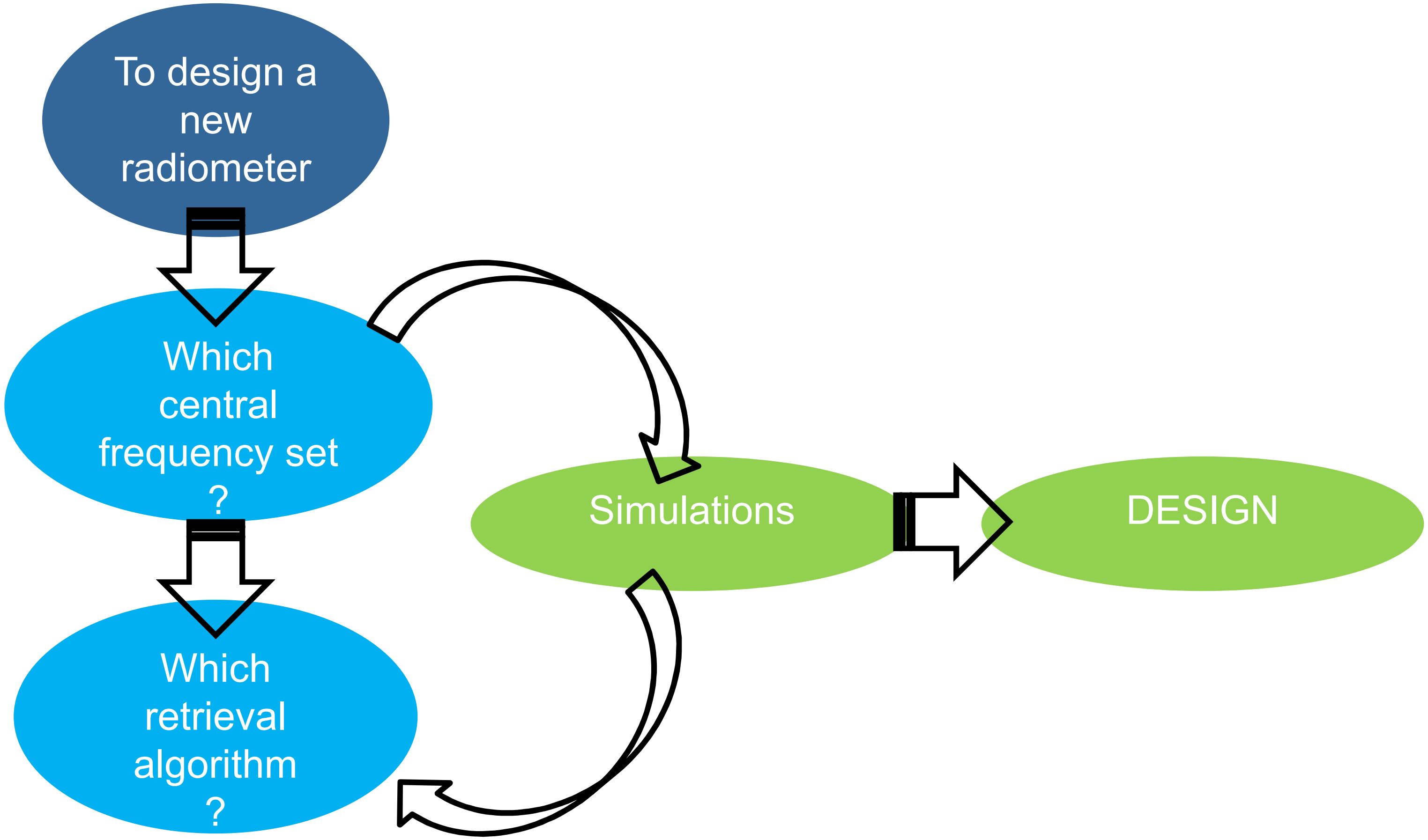
Task 2: Instrument Design: sensitivity

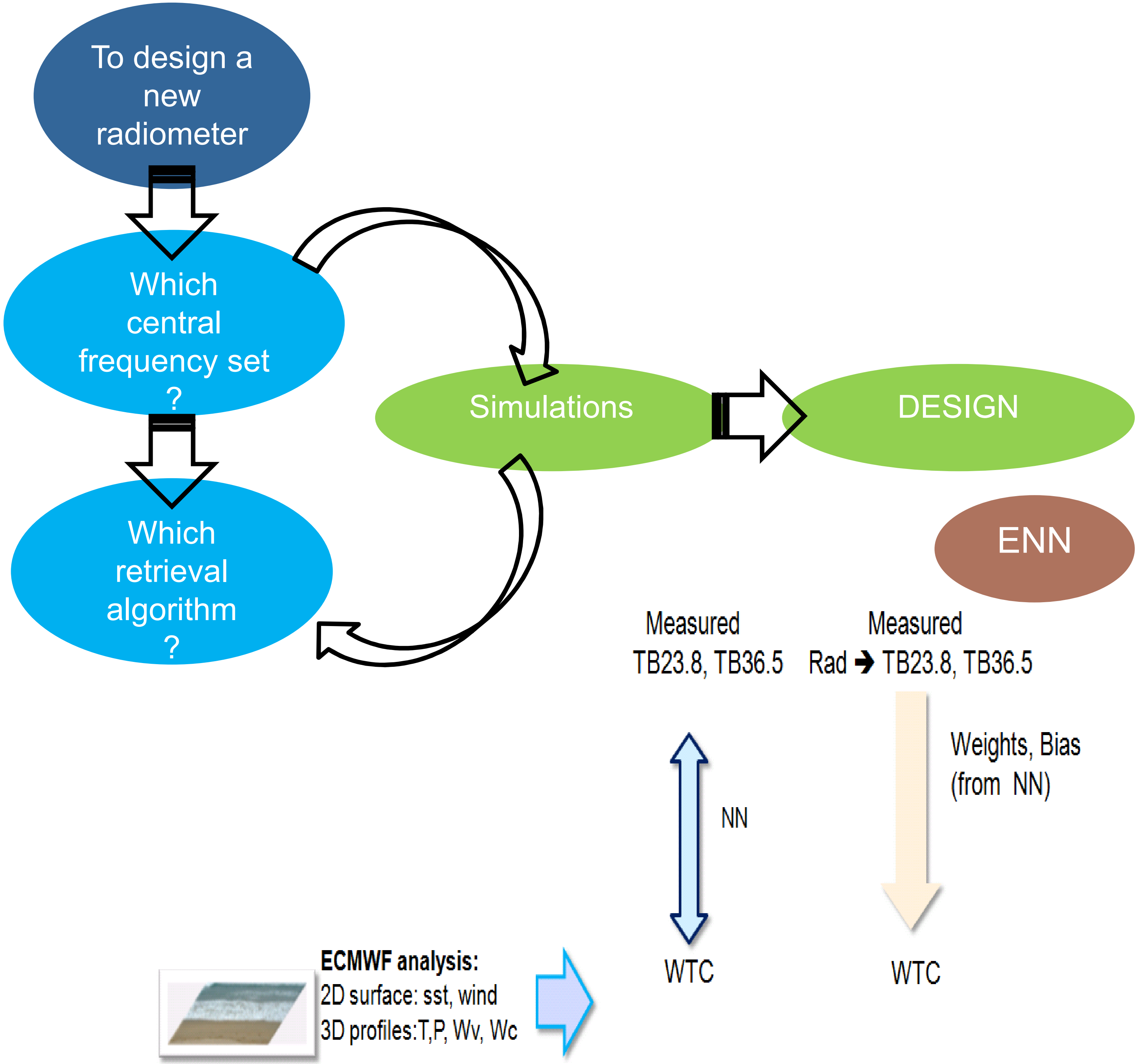
- **Assumes EoL Conditions:**
- **Sun Synchronous (5km)**

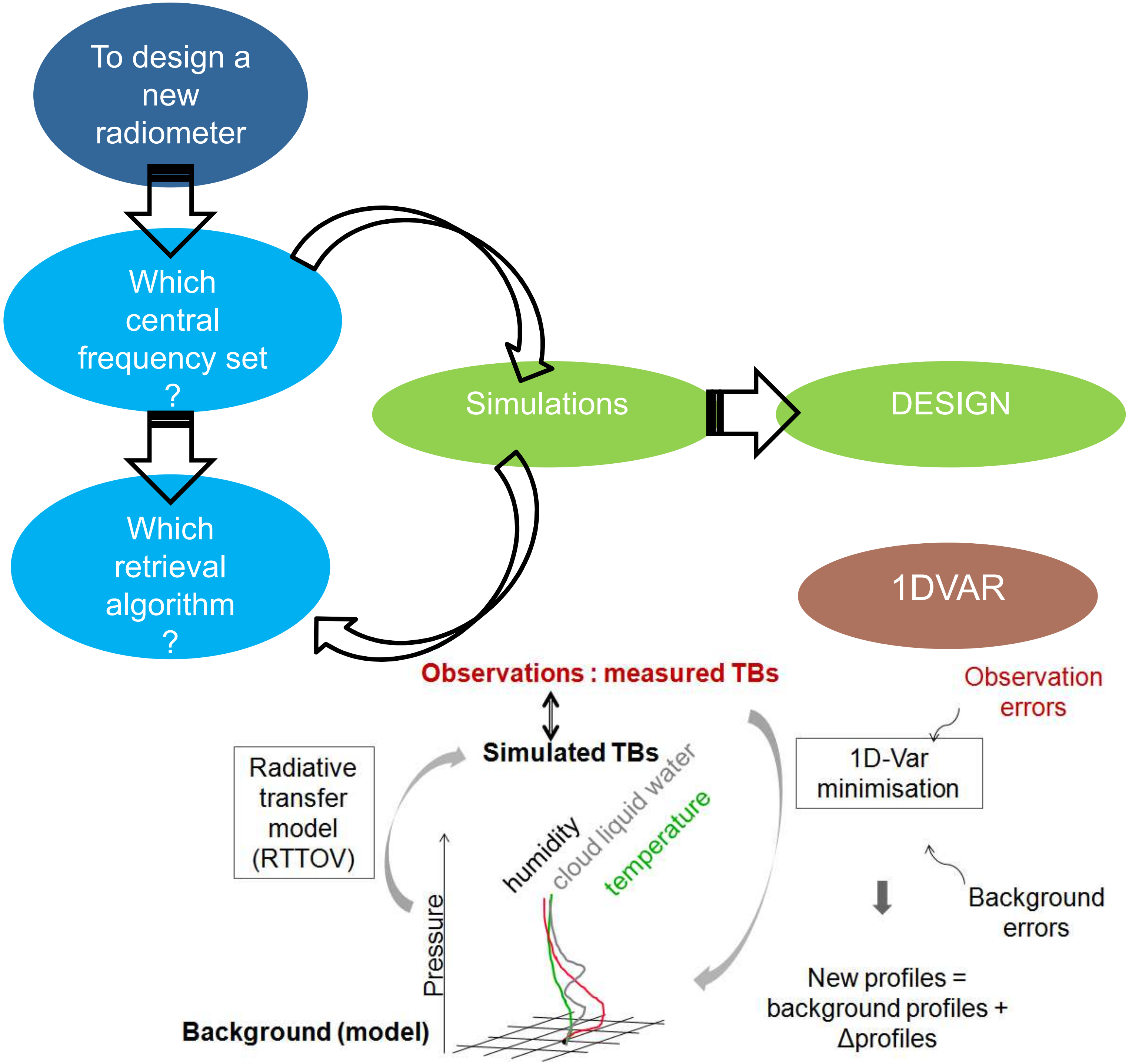
Channel no.	Centre Freq (GHz)	Preselected BW(MHz)	Ant Loss(dB)	Trec (K)	Tsys (K)	NeΔT (K) frontend	NeΔT (K) cal noise	NeΔT (K) Th ΔG/G	NeΔT (K) Total 20% margin RSS	ave factor	Ave NeΔT (K)	Req'mt
1	18.7	200	0.9	225	344	0.05	0.08	0.07	0.13	1.73	**0.08**	0.15
2	23.8	400	0.9	264	392	0.04	0.06	0.07	0.12	1.73	**0.07**	0.15
3	36.5	200	0.9	335	479	0.06	0.10	0.08	0.16	1.73	**0.09**	0.15
4	53.596	400	0.5	351	429	0.04	0.07	0.07	0.12	1.41	**0.09**	0.2
5	89	3000	0.6	450	560	0.02	0.03	0.09	0.11	1.00	**0.11**	0.2
6	110.65	400	0.8	627	812	0.06	0.10	0.11	0.19	1.00	**0.20**	0.25
7	118.75	400	0.8	627	812	0.06	0.10	0.11	0.19	1.00	**0.20**	0.25
8	165.5	1350	0.9	1048	1356	0.05	0.08	0.17	0.23	1.00	**0.23**	0.30
9	183.311-11.0	2000	0.9	957	1244	0.04	0.06	0.16	0.21	1.00	**0.21**	0.30

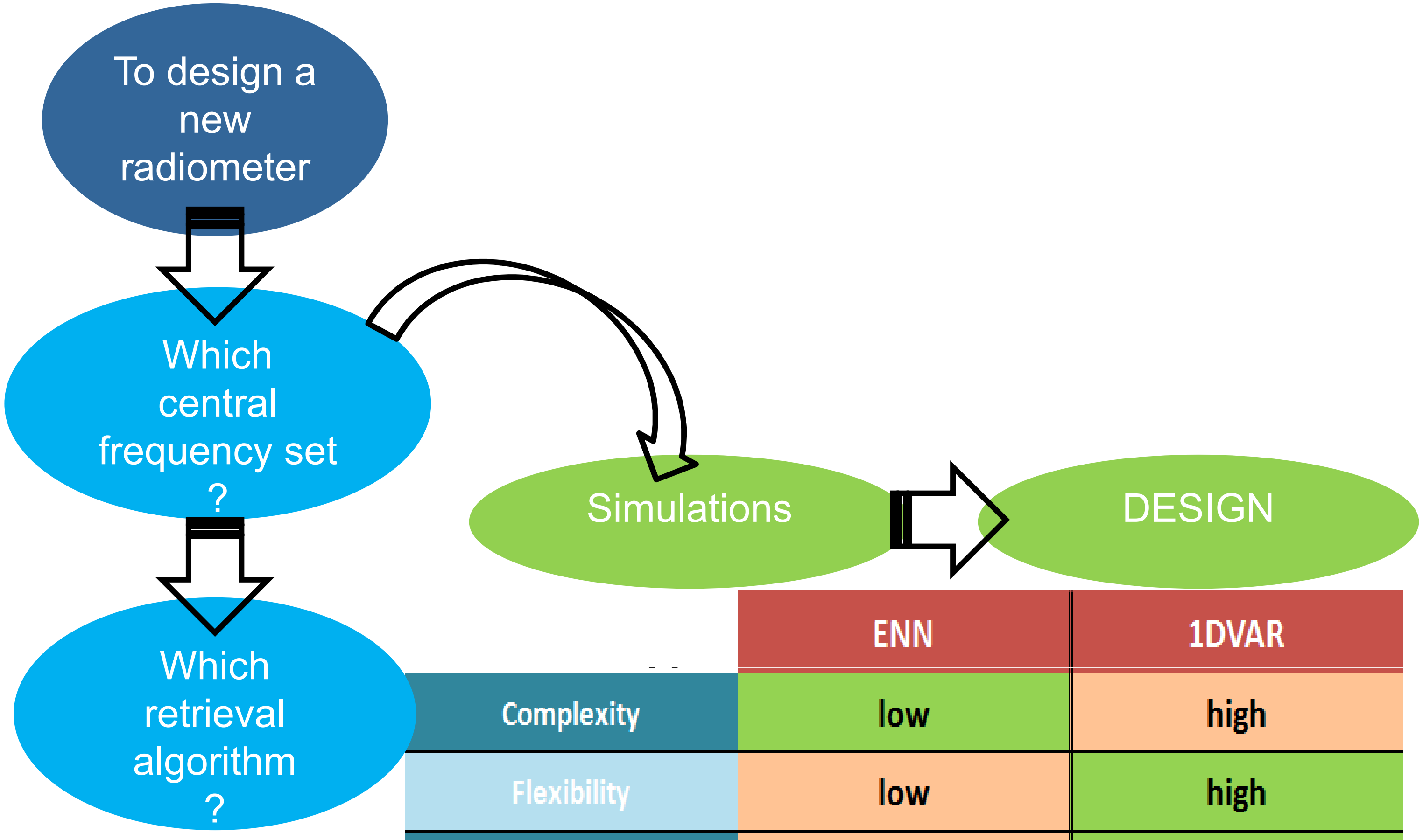
Scene Temp	313	K
Cold Cal Temp	3	K
Hot Cal Temp	300	K
Tau scene	758.00	ms
Tau cold cal	79	ms
Tau hot cal	79	ms
Tau cal effective	158	ms
Cal Ave Factor	2	
ΔG/ΔT	0.05	dB/°C
ΔT/Δt	0.0050	°C/s
Intercal period	3.03	s

High constraints on sensitivity
Both hot and cold calibration
are recommended for thermal stability

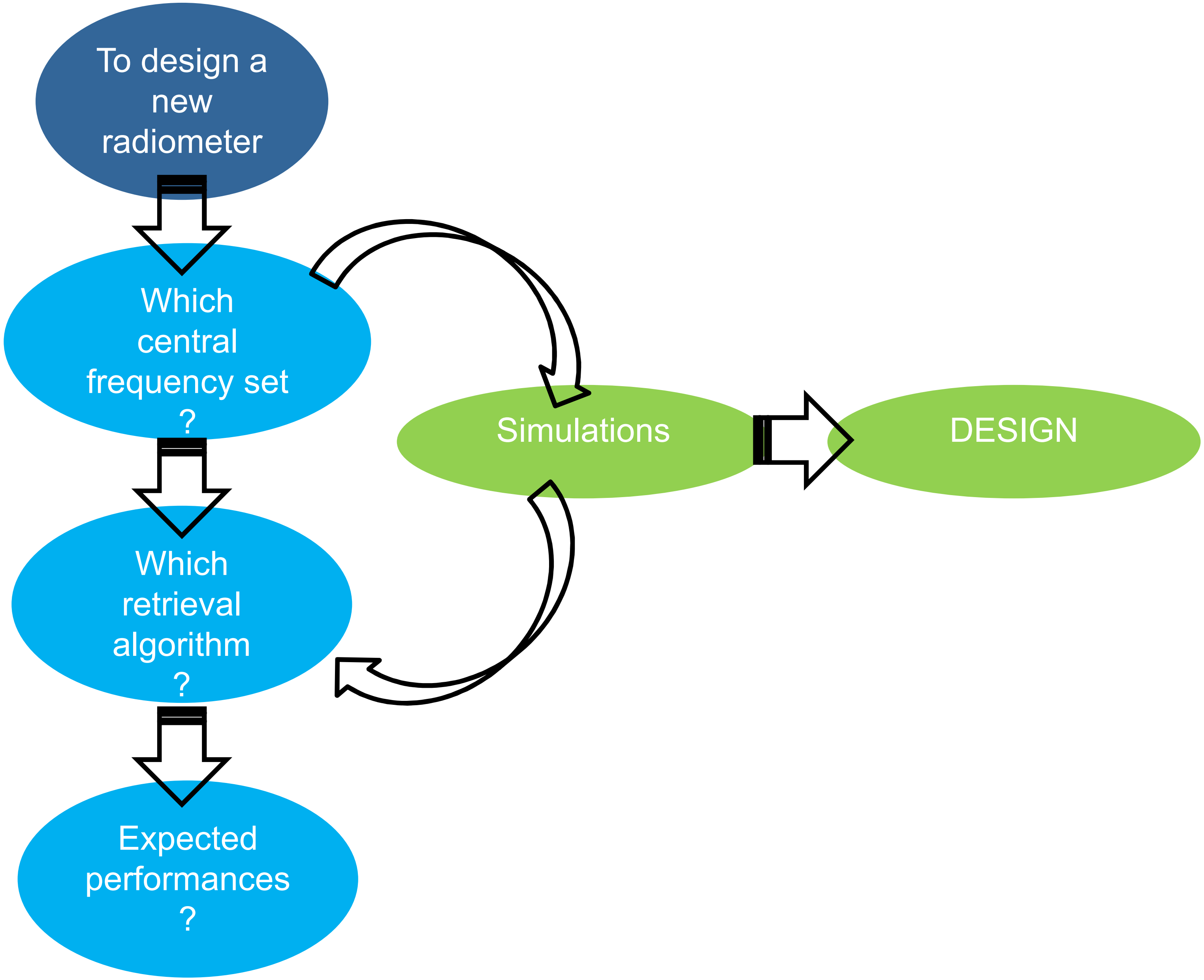

To design a new radiometer
Which central frequency set ?
Which retrieval algorithm ?
Simulations
DESIGN

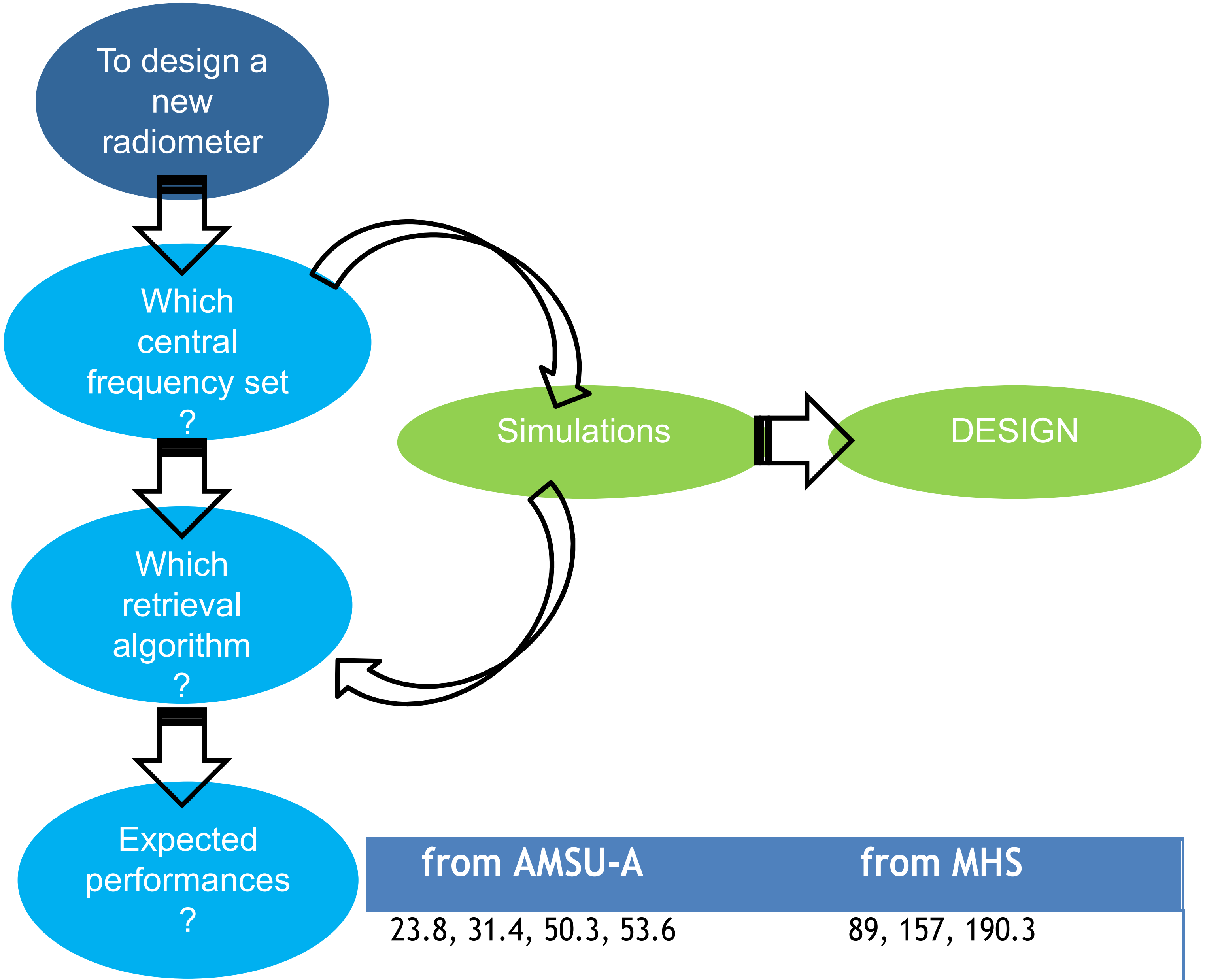

To design a new radiometer
Which central frequency set ?
Which retrieval algorithm ?
Simulations
DESIGN
ENN
Measured
TB23.8, TB36.5
Measured
Rad → TB23.8, TB36.5
NN
Weights, Bias
(from NN)
WTC
WTC
ECMWF analysis:
2D surface: sst, wind
3D profiles:T,P, Wv, Wc


To design a new radiometer
Which central frequency set ?
Which retrieval algorithm ?
Simulations
DESIGN
1DVAR
Observations : measured TBs
Observation errors
Simulated TBs
Radiative transfer model (RTTOV)
1D-Var minimisation
humidity
cloud liquid water
temperature
Pressure
Background errors
New profiles = background profiles + Δprofiles
Background (model)

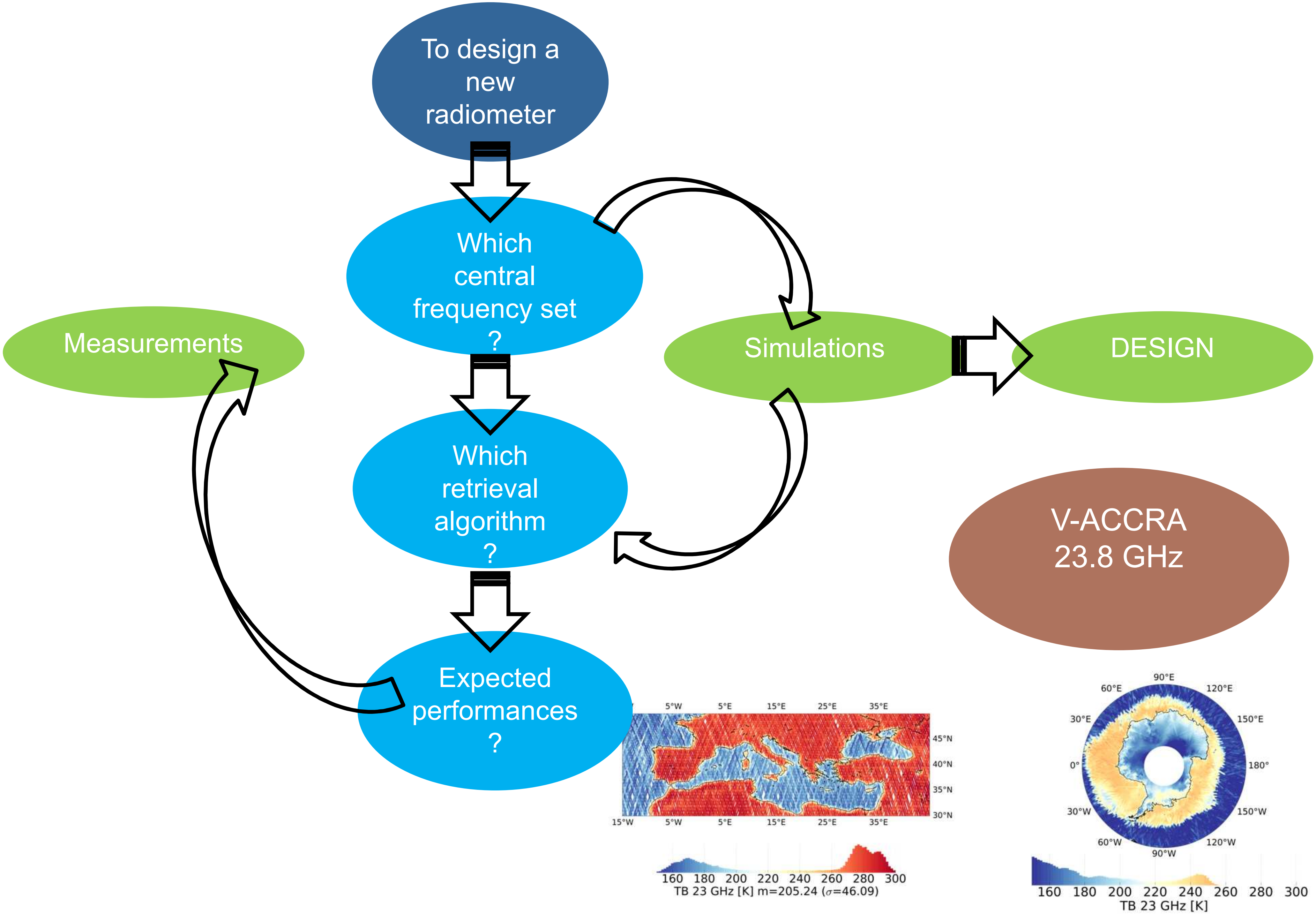


	ENN	1DVAR
Complexity	low	high
Flexibility	low	high
Spatial resolution	implicit	explicit
Open Ocean Performances	good but limited (TB vs model WTC)	optimal
Coastal Performances	equal spatial resolution	below spatial resolution
Ice/Sea Ice	good but limited (TB vs model WTC)	TBC

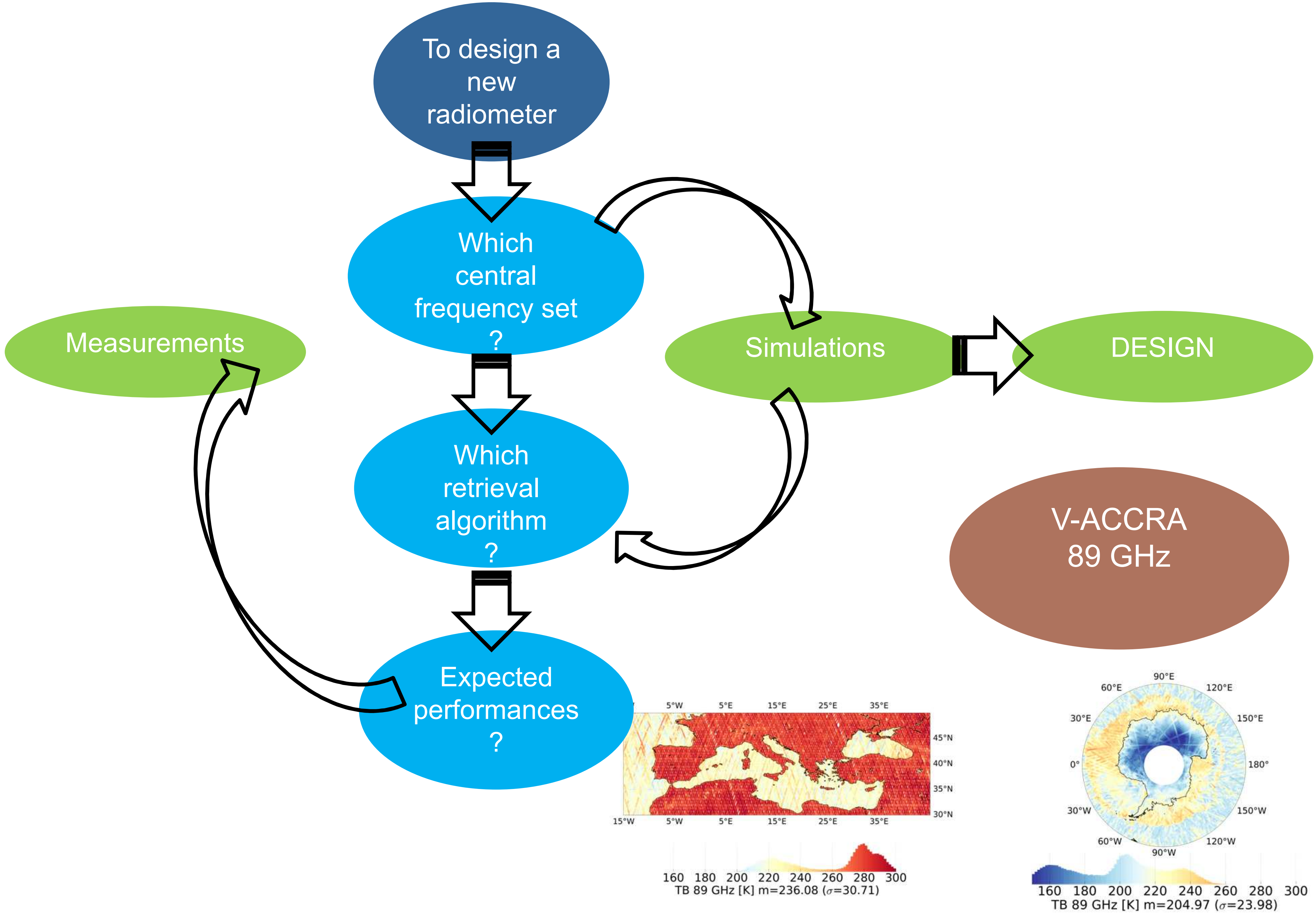

To design a new radiometer
Which central frequency set ?
Which retrieval algorithm ?
Expected performances ?
Simulations
DESIGN

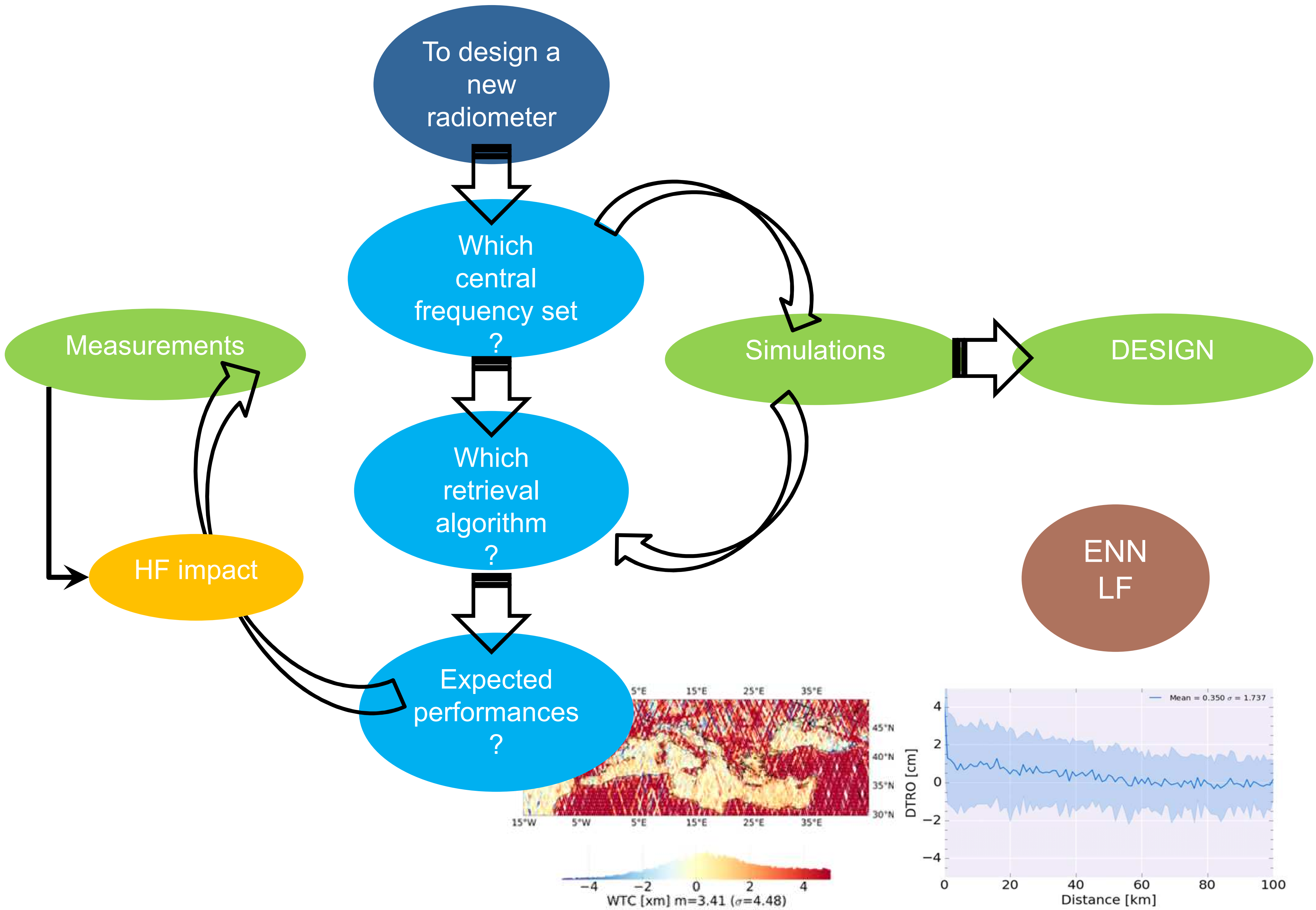


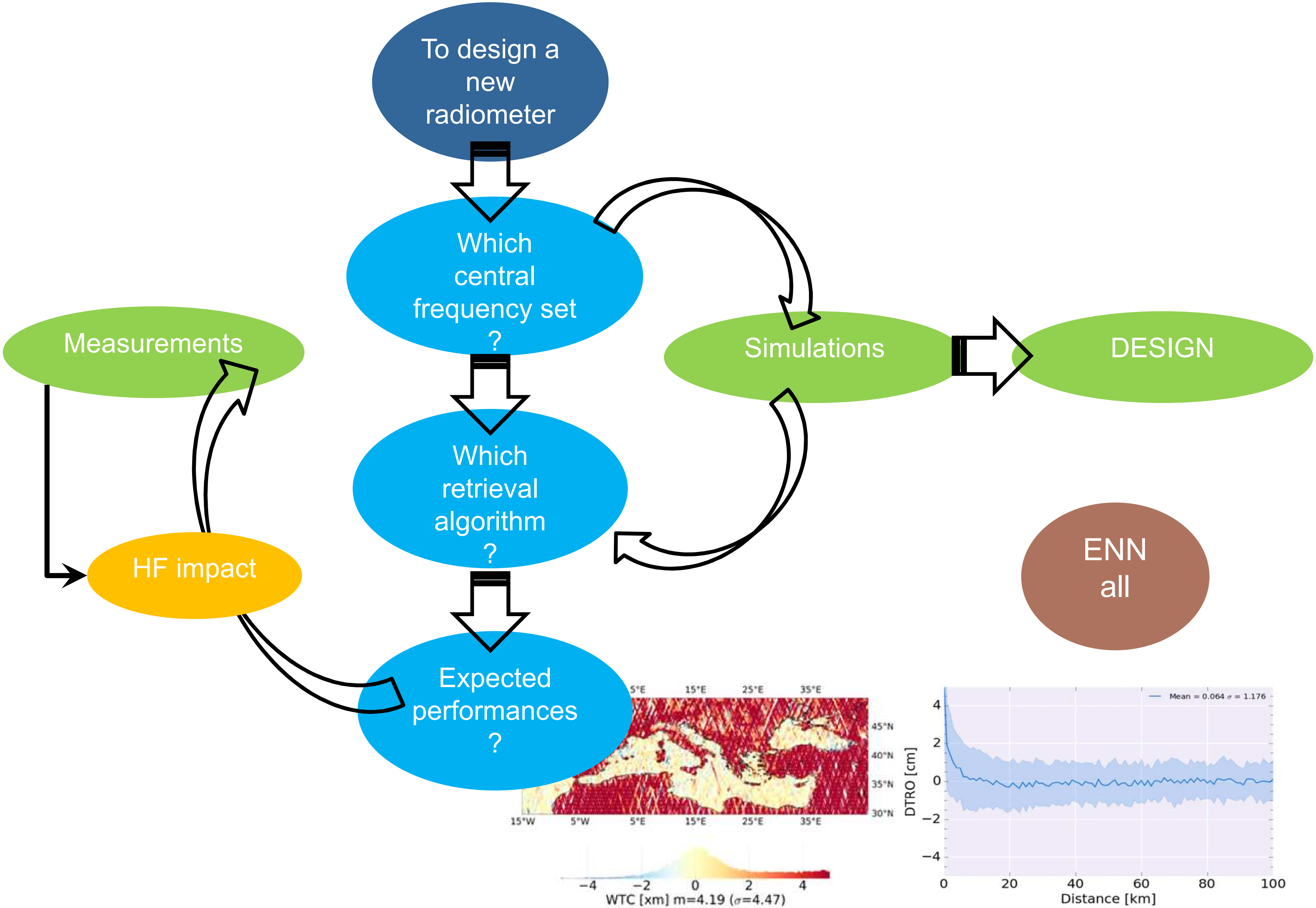
from AMSU-A	from MHS
23.8, 31.4, 50.3, 53.6	89, 157, 190.3



To design a new radiometer
Which central frequency set ?
Which retrieval algorithm ?
Expected performances ?
Measurements
Simulations
DESIGN
V-ACCRA 23.8 GHz
TB 23 GHz [K] m=205.24 (σ=46.09)
TB 23 GHz [K]


To design a new radiometer
Which central frequency set ?
Which retrieval algorithm ?
Expected performances ?
Measurements
Simulations
DESIGN
V-ACCRA
89 GHz
160 180 200 220 240 260 280 300
TB 89 GHz [K] m=236.08 (σ=30.71)
160 180 200 220 240 260 280 300
TB 89 GHz [K] m=204.97 (σ=23.98)


To design a new radiometer
Which central frequency set ?
Which retrieval algorithm ?
Expected performances ?
Measurements
HF impact
Simulations
DESIGN
ENN LF
WTC [xm] m=3.41 (σ=4.48)
Mean = 0.350 σ = 1.737
DTRO [cm]
Distance [km]


To design a new radiometer
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HF impact
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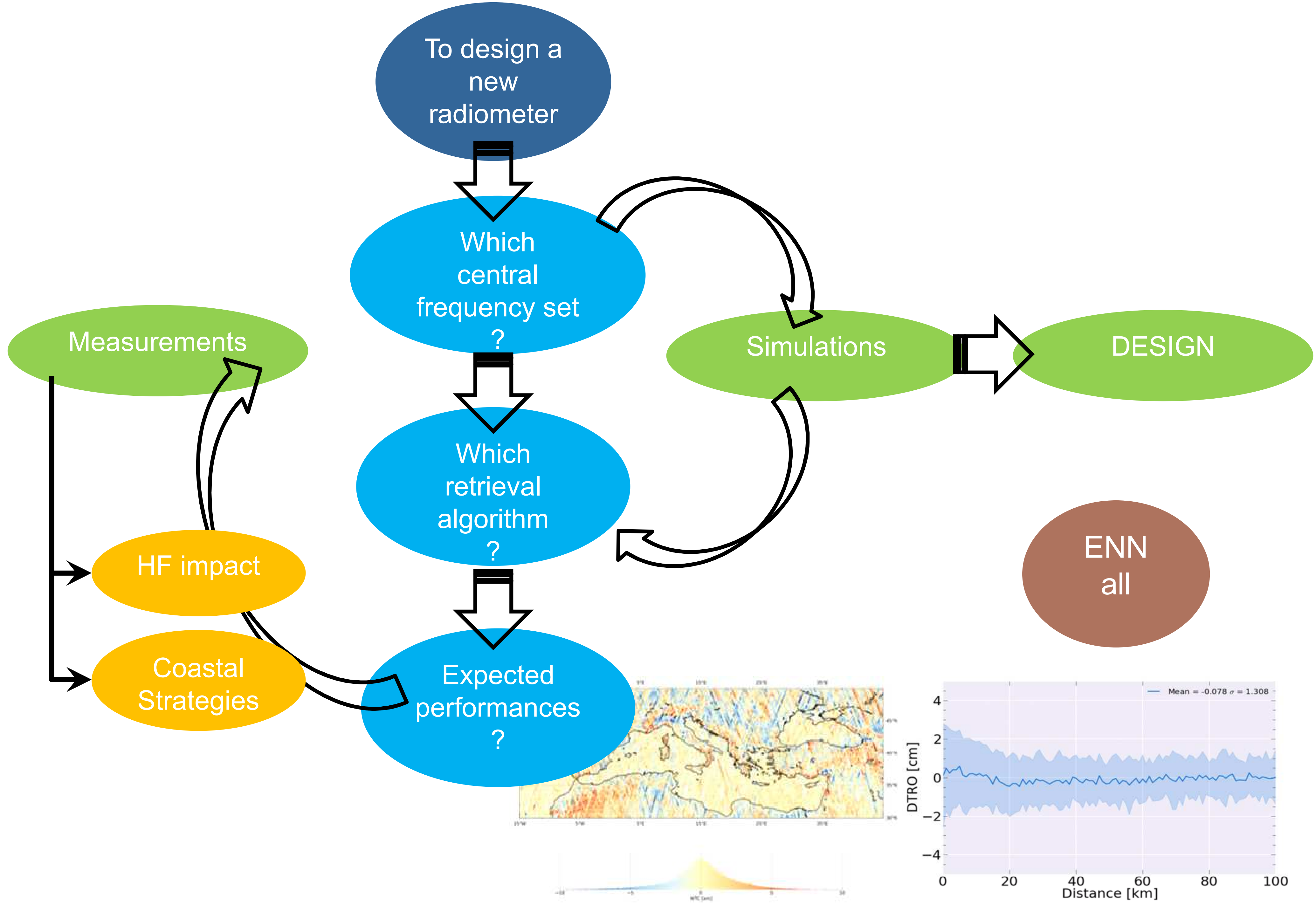
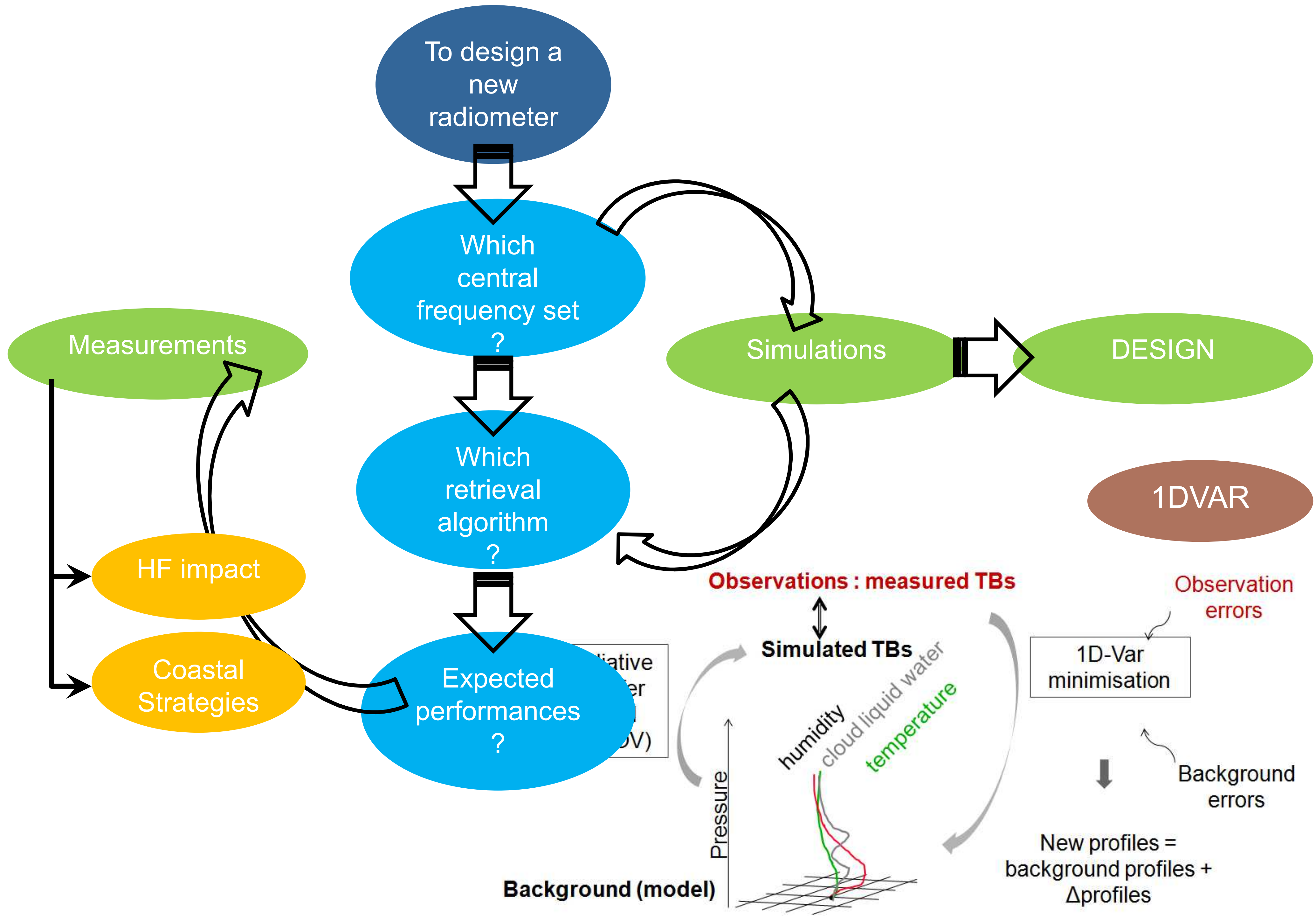
DESIGN
ENN all
WTC [xm] m=4.19 (σ=4.47)
DTRO [cm]
Distance [km]
Mean = 0.064 σ = 1.176


To design a new radiometer
Which central frequency set ?
Which retrieval algorithm ?
Expected performances ?
Measurements
HF impact
Coastal Strategies
Simulations
DESIGN
ENN all
Mean = -0.078 σ = 1.308
DTRO [cm]
Distance [km]


To design a new radiometer
Which central frequency set ?
Which retrieval algorithm ?
Expected performances ?
Measurements
HF impact
Coastal Strategies
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DESIGN
1DVAR
Observations : measured TBs
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humidity
cloud liquid water
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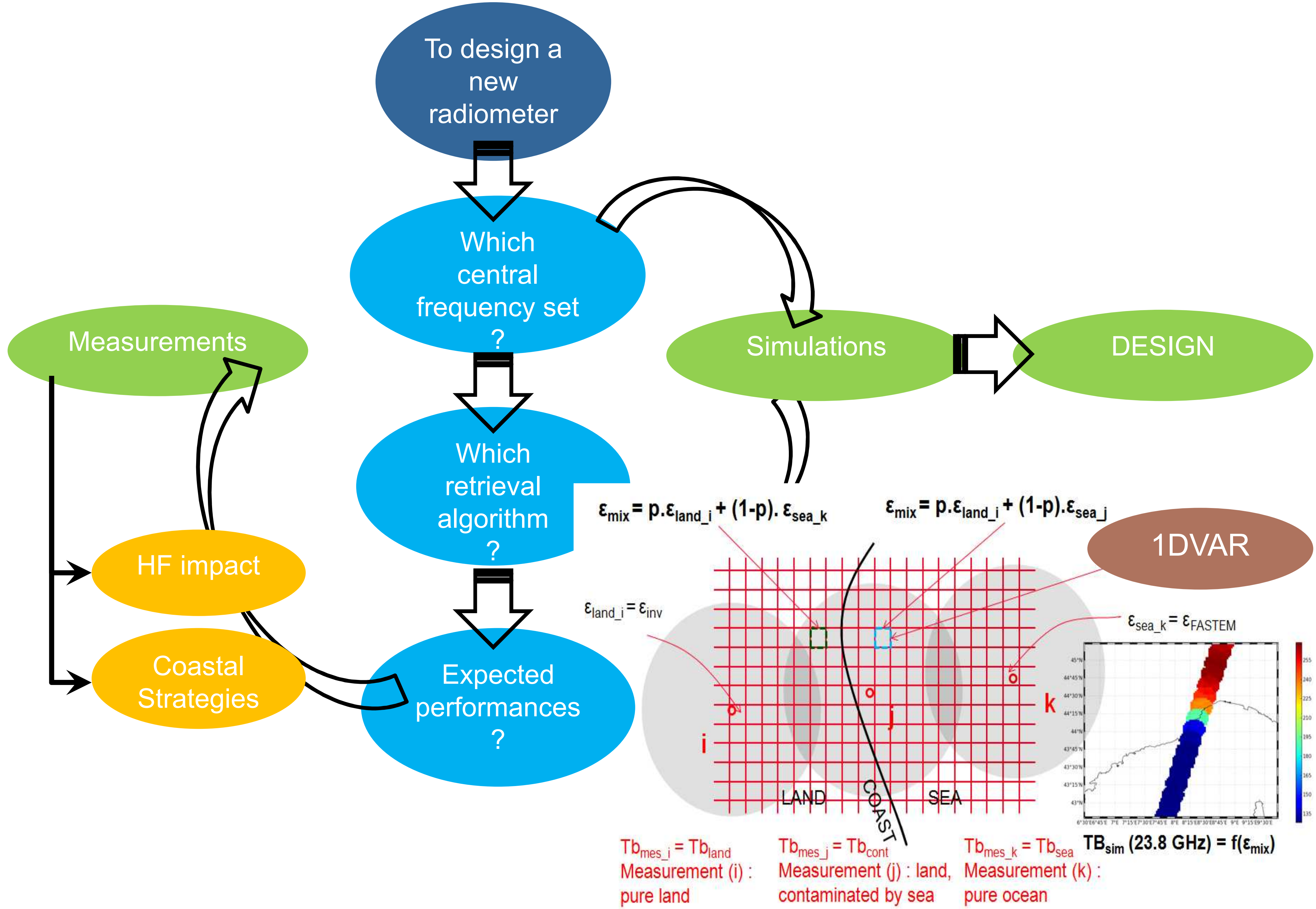
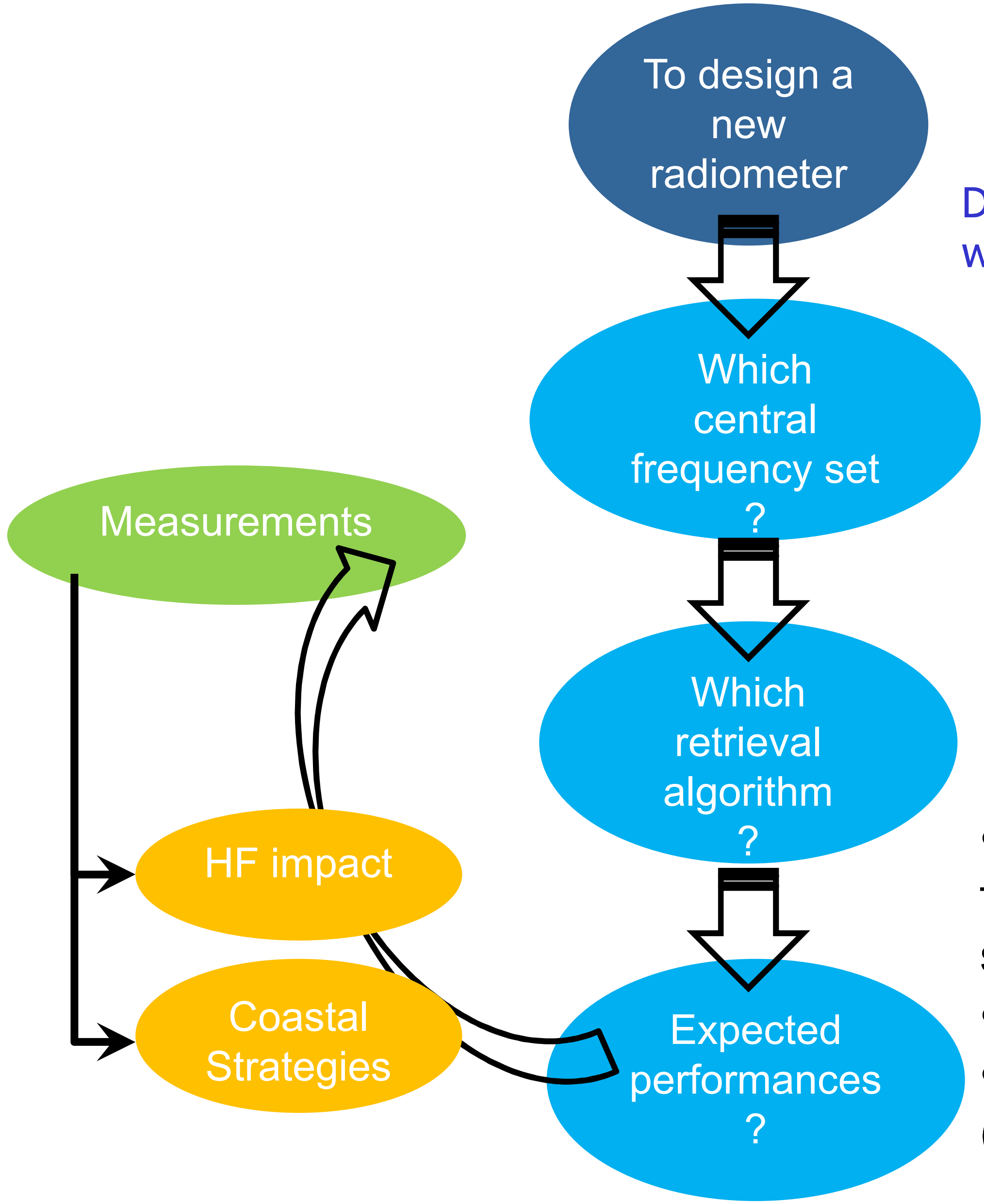
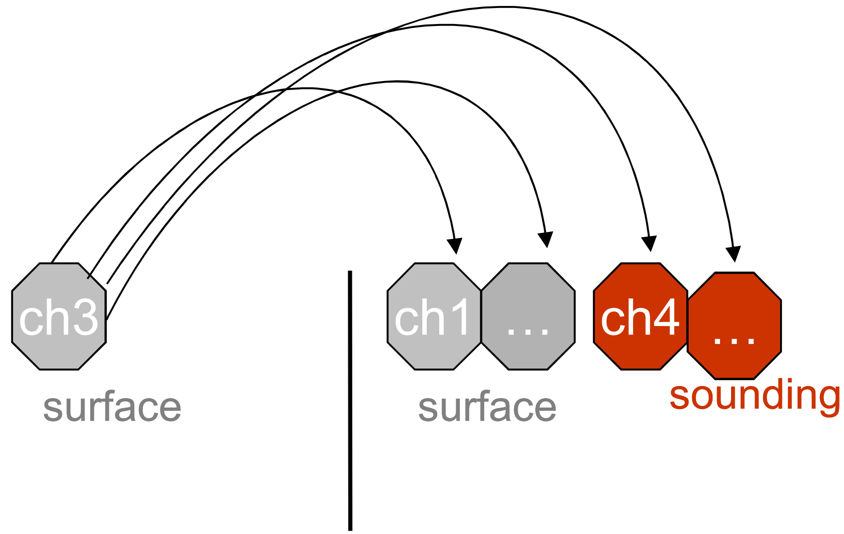
Pressure
Background (model)
Observation errors
1D-Var minimisation
Background errors
New profiles = background profiles + Δprofiles



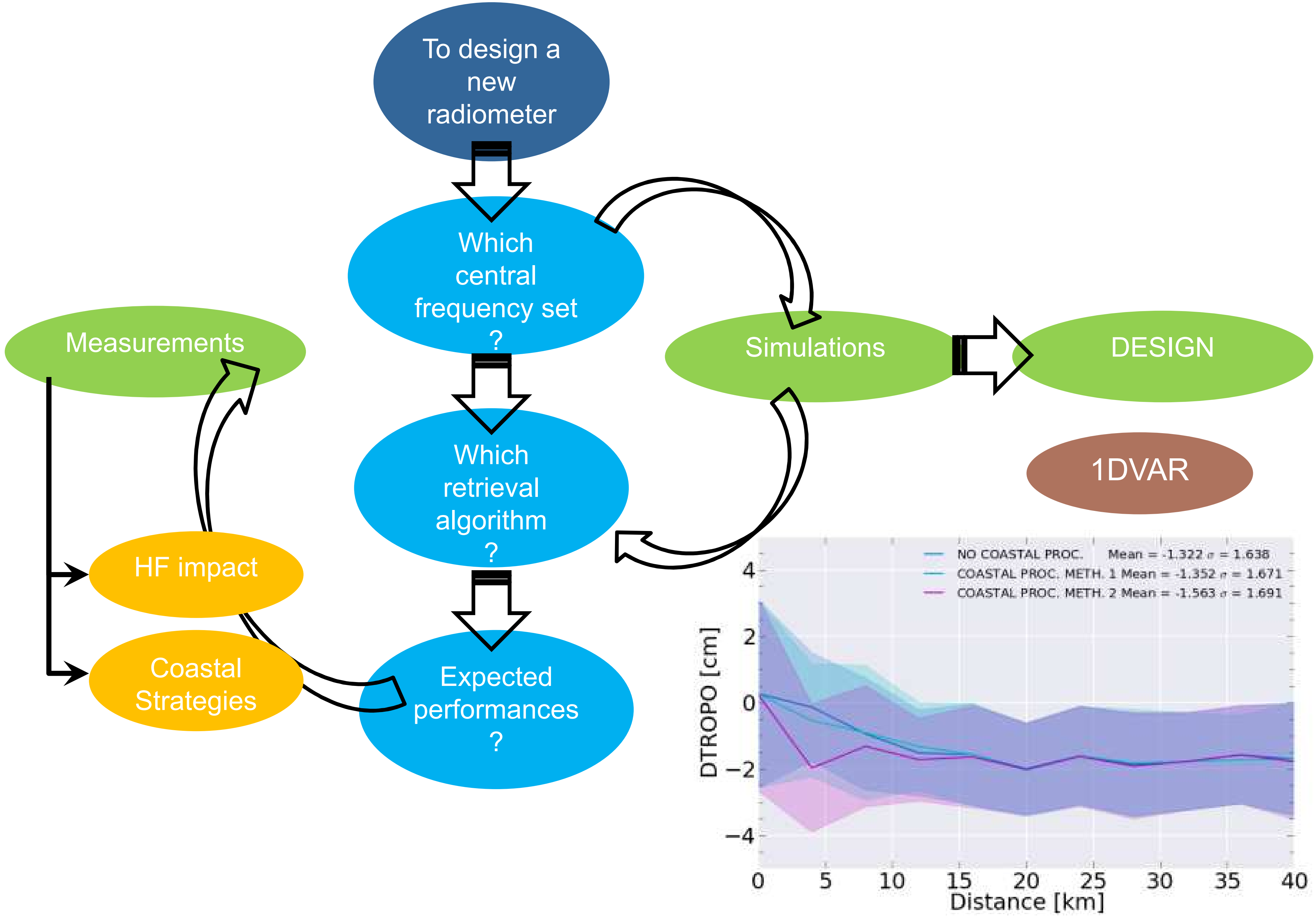
To design a new radiometer
Which central frequency set ?
Which retrieval algorithm ?
Expected performances ?
Measurements
HF impact
Coastal Strategies
Simulations
DESIGN
1DVAR
$\varepsilon_{mix} = p.\varepsilon_{land\_i} + (1\text{-}p).\varepsilon_{sea\_k}$
$\varepsilon_{mix} = p.\varepsilon_{land\_i} + (1\text{-}p).\varepsilon_{sea\_j}$
$\varepsilon_{land\_i} = \varepsilon_{inv}$
$\varepsilon_{sea\_k} = \varepsilon_{FASTEM}$
i
j
k
LAND
COAST
SEA
TB_{sim} (23.8 GHz) = $f(\varepsilon_{mix})$
$Tb_{mes\_i} = Tb_{land}$
Measurement (i) : pure land
$Tb_{mes\_j} = Tb_{cont}$
Measurement (j) : land, contaminated by sea
$Tb_{mes\_k} = Tb_{sea}$
Measurement (k) : pure ocean



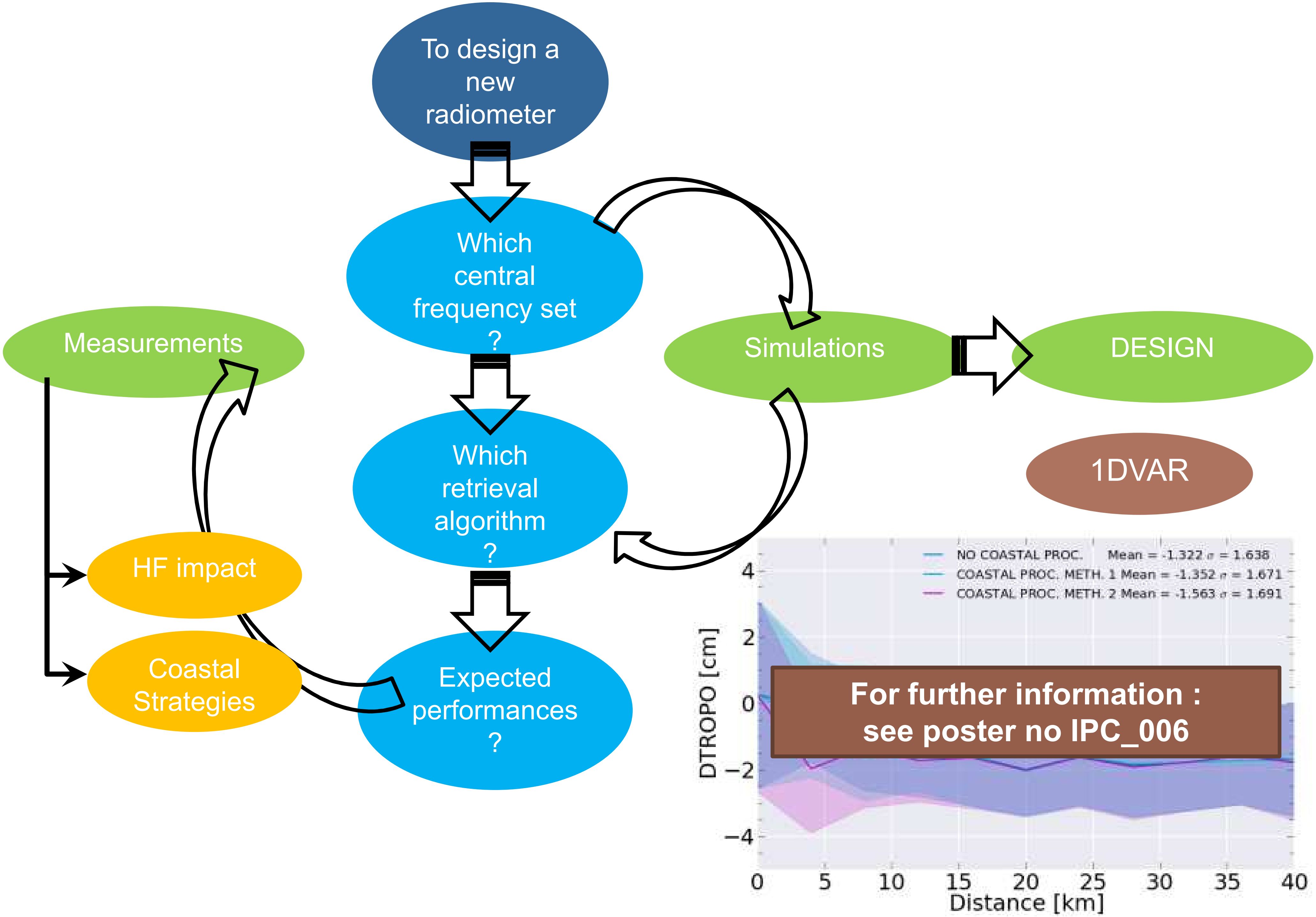
Dynamical estimation of emissivity at a well selected window channel



- Choose the best channel : closest in frequency or the most sensitive one to the surface ?
- + account for any changes at the surface
- +account for instrumental caracteristics (viewing angle, polar)



To design a new radiometer
Which central frequency set ?
Which retrieval algorithm ?
Expected performances ?
Measurements
HF impact
Coastal Strategies
Simulations
DESIGN
1DVAR
NO COASTAL PROC. Mean = -1.322 σ = 1.638
COASTAL PROC. METH. 1 Mean = -1.352 σ = 1.671
COASTAL PROC. METH. 2 Mean = -1.563 σ = 1.691
DTROPO [cm]
Distance [km]



To design a new radiometer
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DESIGN
1DVAR
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COASTAL PROC. METH. 1 Mean = -1.352 σ = 1.671
COASTAL PROC. METH. 2 Mean = -1.563 σ = 1.691
DTROPO [cm]
Distance [km]
For further information :
see poster no IPC_006

Conclusion

- The ACCRA study gathers experts with skills on hardware and retrieval aspects
- In order to properly define the optimal instrumental design, a back and forth approach between design and algorithm performances is applied

Conclusion

- A set of 6 observation frequencies has been selected with additionnal information on water vapour, atmospheric situation, surface characterization

- Requirements and a design are proposed

Conclusion

- 1DVAR approach is a very flexible method. The same algorithm can be applied to multiple surfaces, it takes the optimal benefits from the observations and the model (not limited by inconsistencies as the empirical NN) and its flexibility allows a downscaling approach.

Thank you for your attention