Clustering of ROTI maps for ionospheric irregularities geolocation

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OUTLINE

01 Introduction

and Motivation of present study

02 Applied techniques

ROTI Maps and Stratification through Clustering

03 Case Studies

Test cases in the study region

04 Summary

01 INTRODUCTION

Ionospheric perturbations -> major issue in GNSS

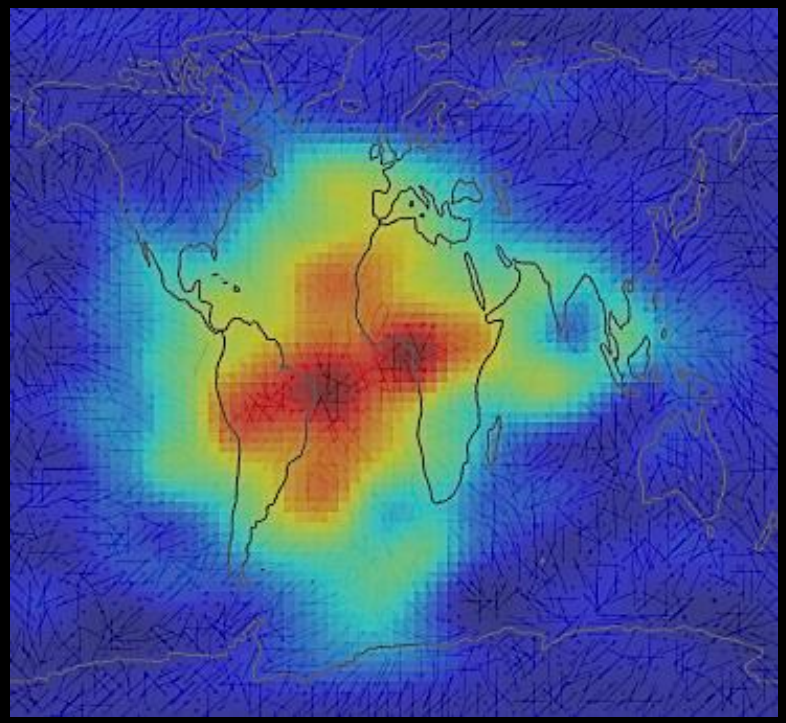
GNSS signals provide valuable information about ionospheric variability and SW phenomena

MOTIVATION

Investigation of an indicator of ionospheric temporal fluctuations to characterize and monitoring a region

Use of data derived from GNSS stations

Use of a sampling technique



02

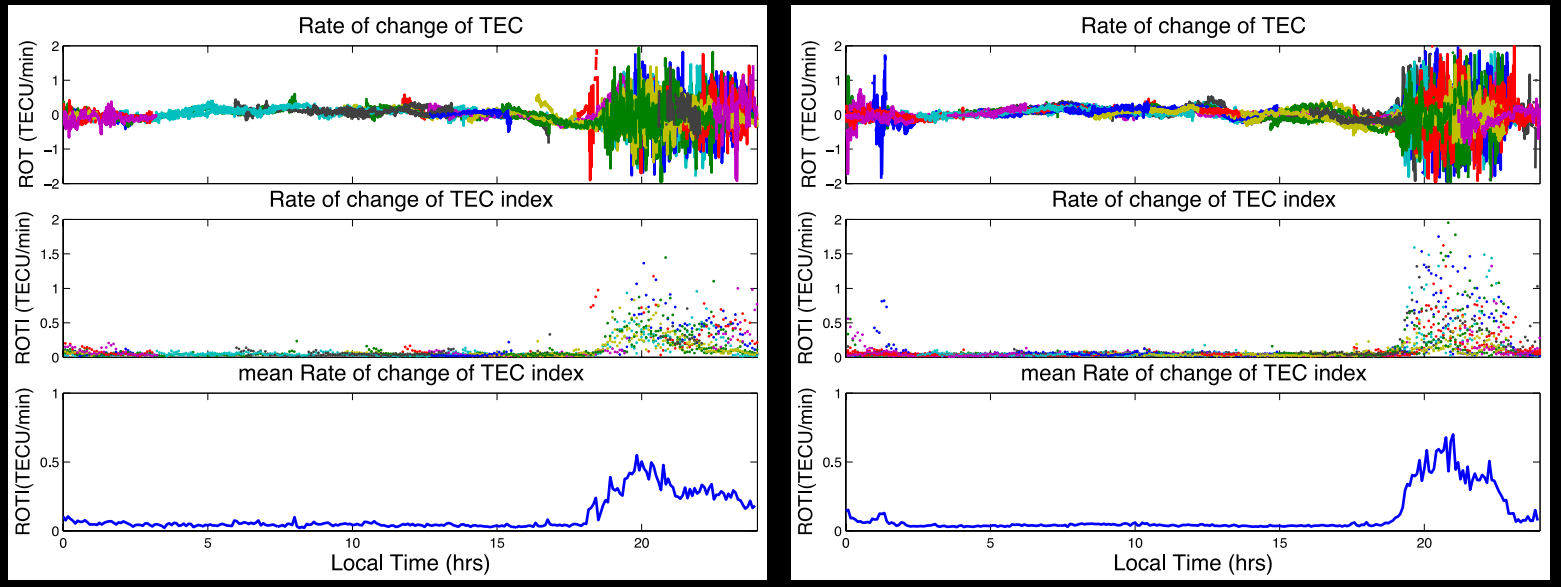
APPLIED TECHNIQUES

ROTI maps, Kriging and Stratification

ROT and ROTI

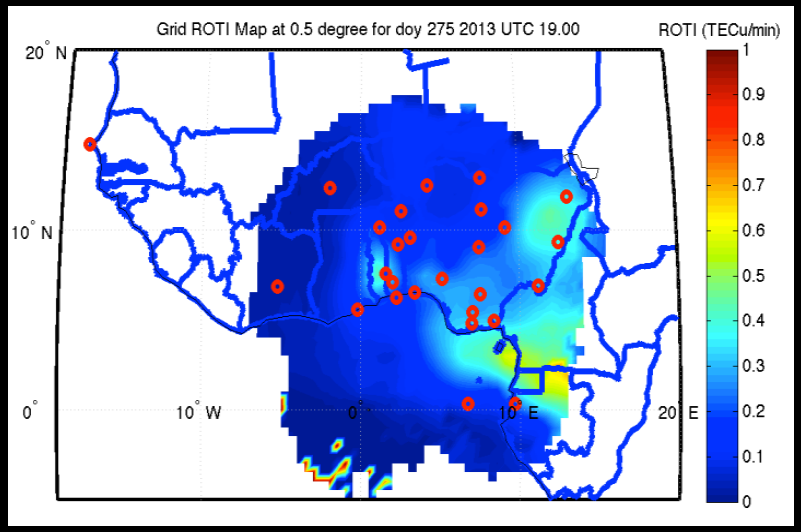
$$ROT = \frac{sTEC_k^i - sTEC_{k-1}^i}{t_k - t_{k-1}}$$

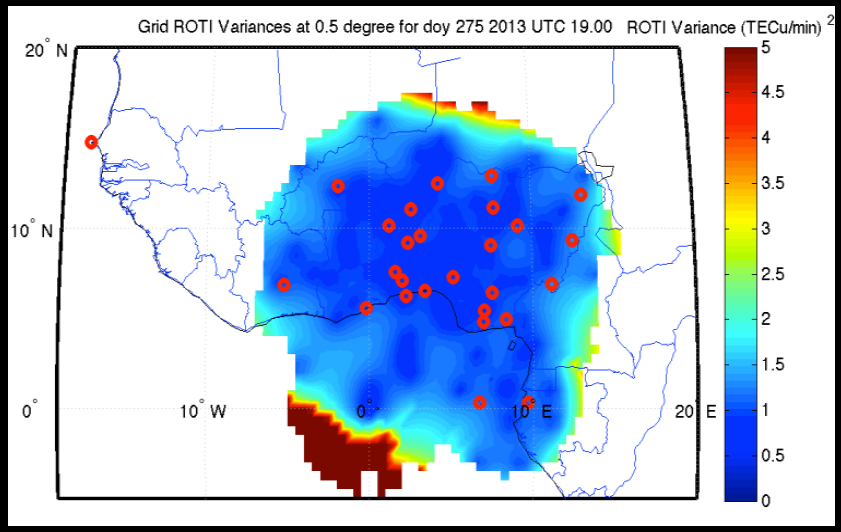
$$ROTI = \sqrt{< ROT^2 > - < ROT >^2}$$



Ionosphere Irregularities during Disturbed Condition of October 2nd, 2013 in West African stations: (left) futy; (right) nklg.

Spatial Interpolation: ROTI Maps





Regional ROTI maps and variance maps after Ordinary Kriging during a geomagnetic disturbed day DOY 275 with presence of irregularities

Blanch, 2002

Spatial Sampling: Clustering

So far most of the indices and spatial means of TEC and ROTI maps have been done through regular grids

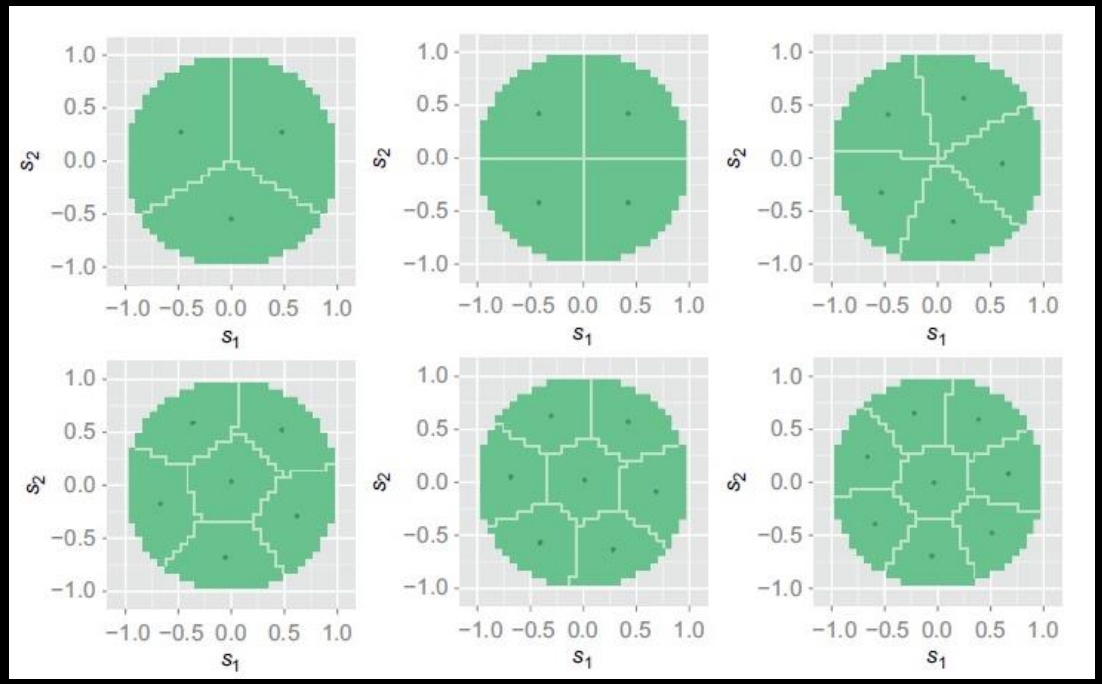
However, an irregular pattern is expected to lead to a more precise spatial mean *(Cochran, 1977)*.

Clustering is the task of grouping a set of objects in such a way that objects in the same group (**cluster**) are more similar (in some sense) to each other than to those in other groups

k-means

$$MSSD = \frac{1}{N}\sum min_j(D_{ij}^2)$$

Walvoort et al, 2009



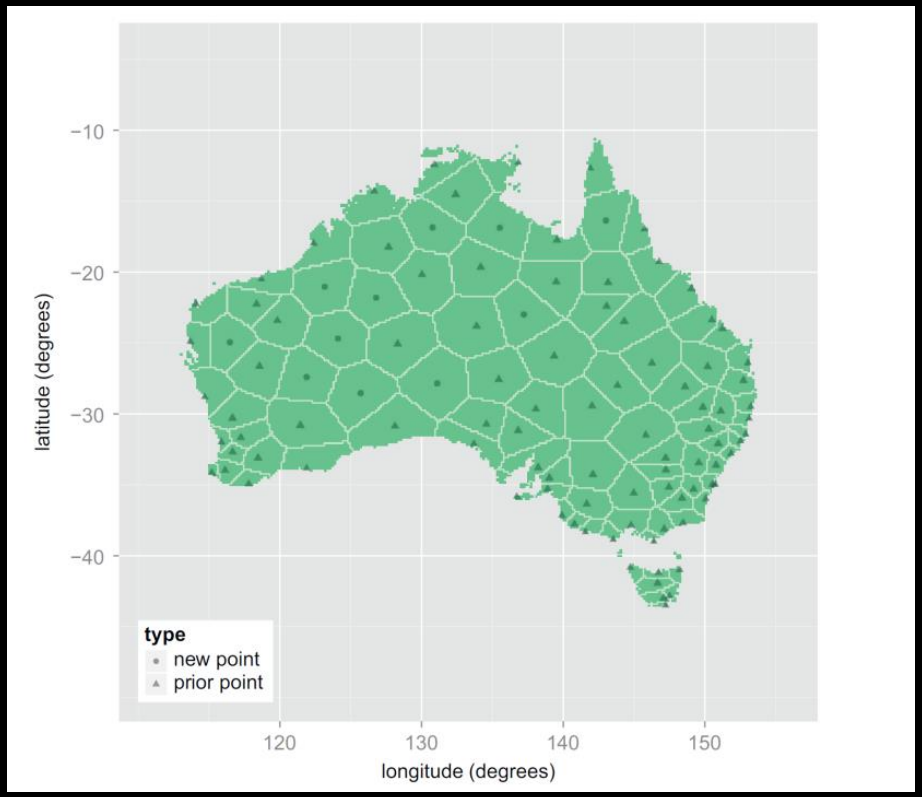
Examples of spatial coverage samples to estimate spatial means of circular shaped region

Spatial Sampling: Clustering

Walvoort et al, 2009

Centroid-Clustering or Partition Clustering

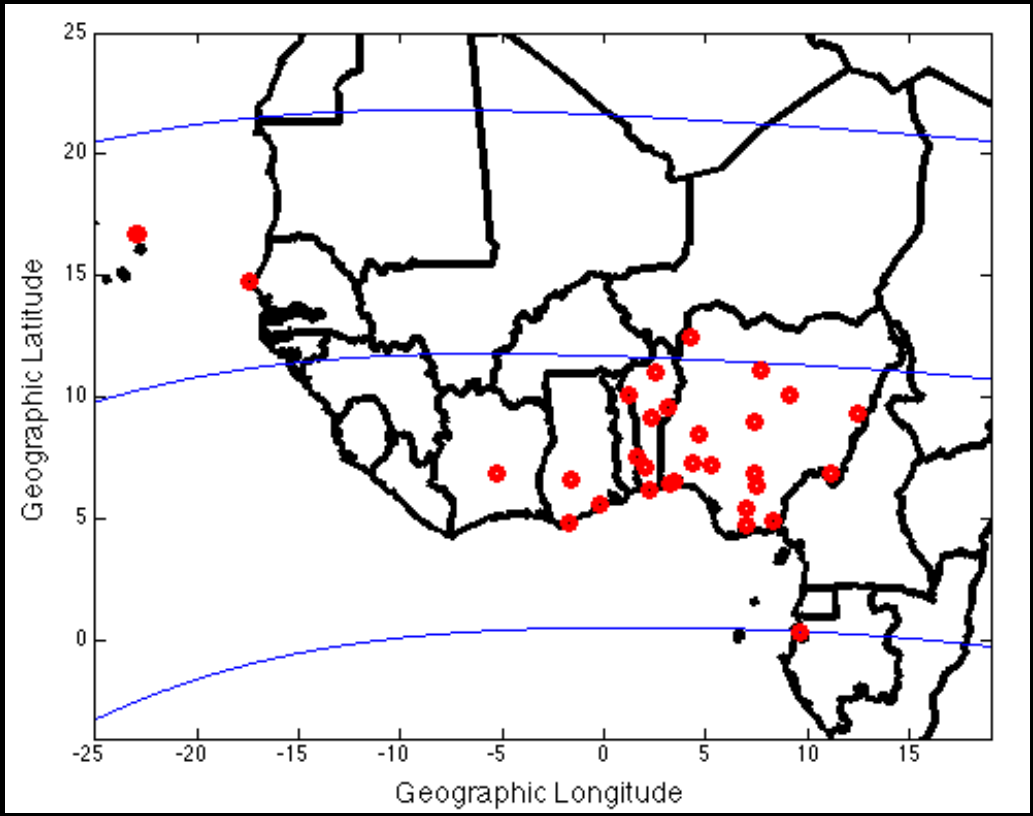
k-means



Spatial infill sample of new climate stations. Existing climate stations (94) are part of the Australian Reference Climate Station (RCS) network.

03 CASE STUDIES

STUDY REGION

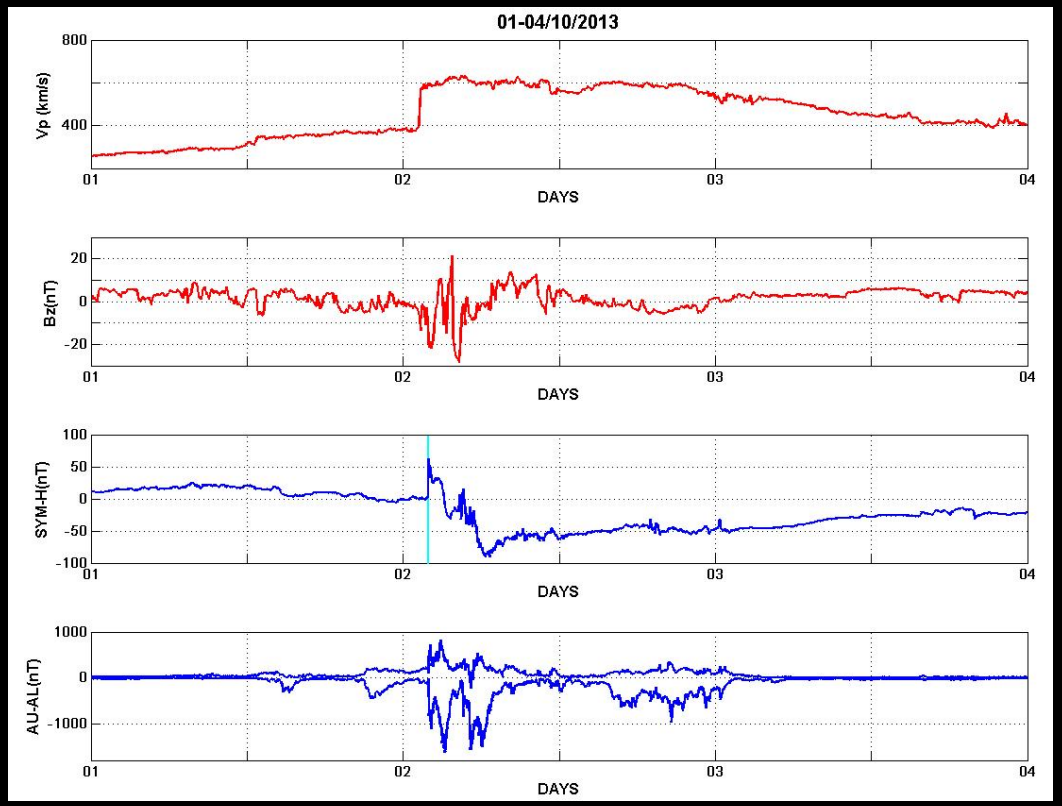


◎ STUDY REGION

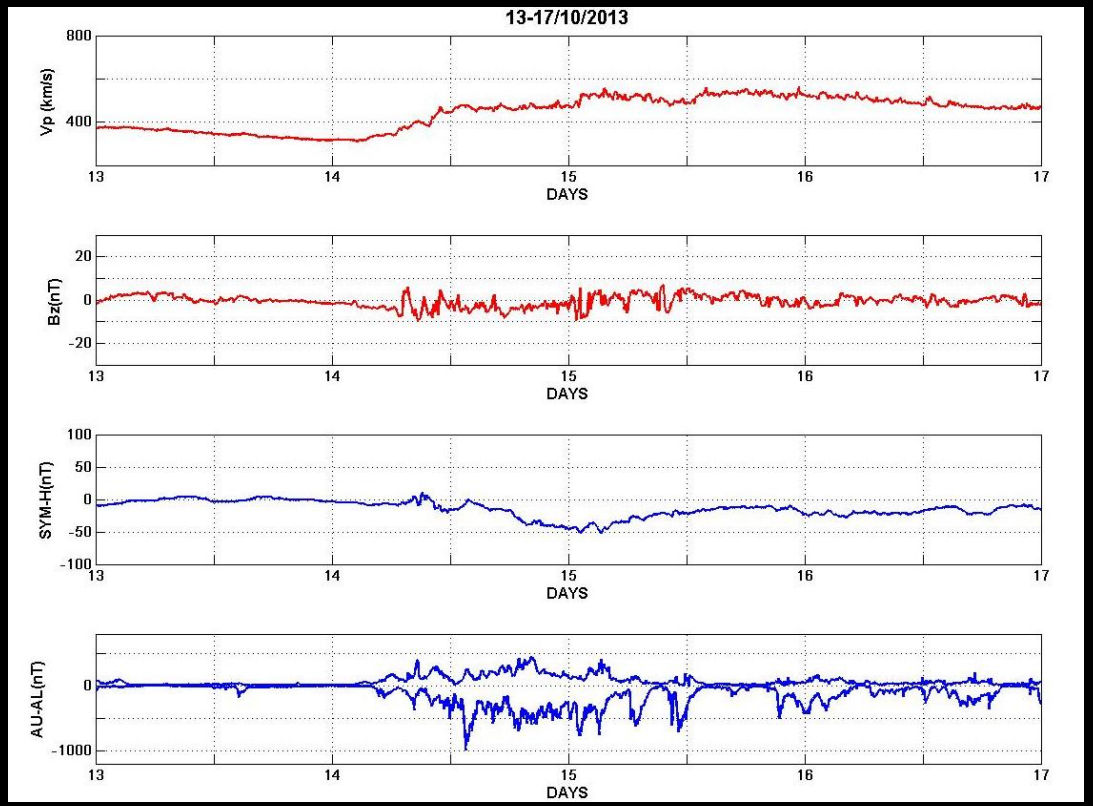
GNSS stations used in the study were located in the Western Sub Saharan African region.

Case Studies

After an analysis of available data and geomagnetic events, disturbed days
2nd and **14th Oct 2013** **(days 275 and 287)** have been selected.



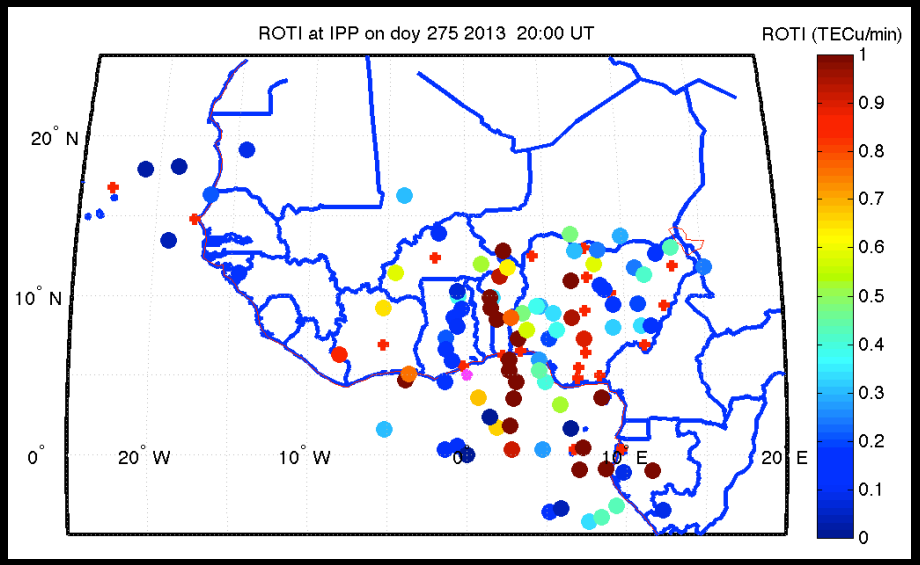
CME impacting the Earth in the early morning on October 2nd at 01.55UT.



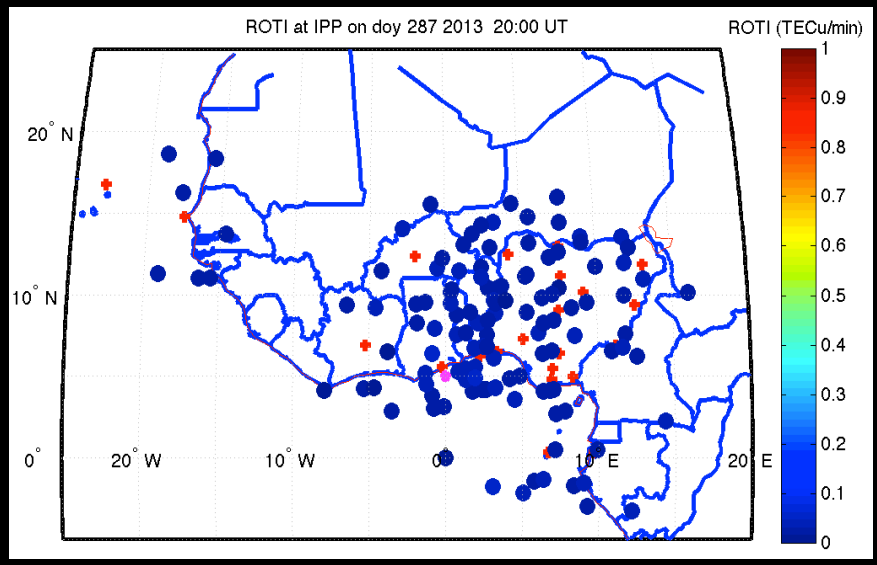
CME and HSSW arrival associated to a coronal hole on 14 Oct 2013.

Test Cases: ROTI

ROTI values at the available GNSS stations pierce points



Day 275 year 2013 with irregularities

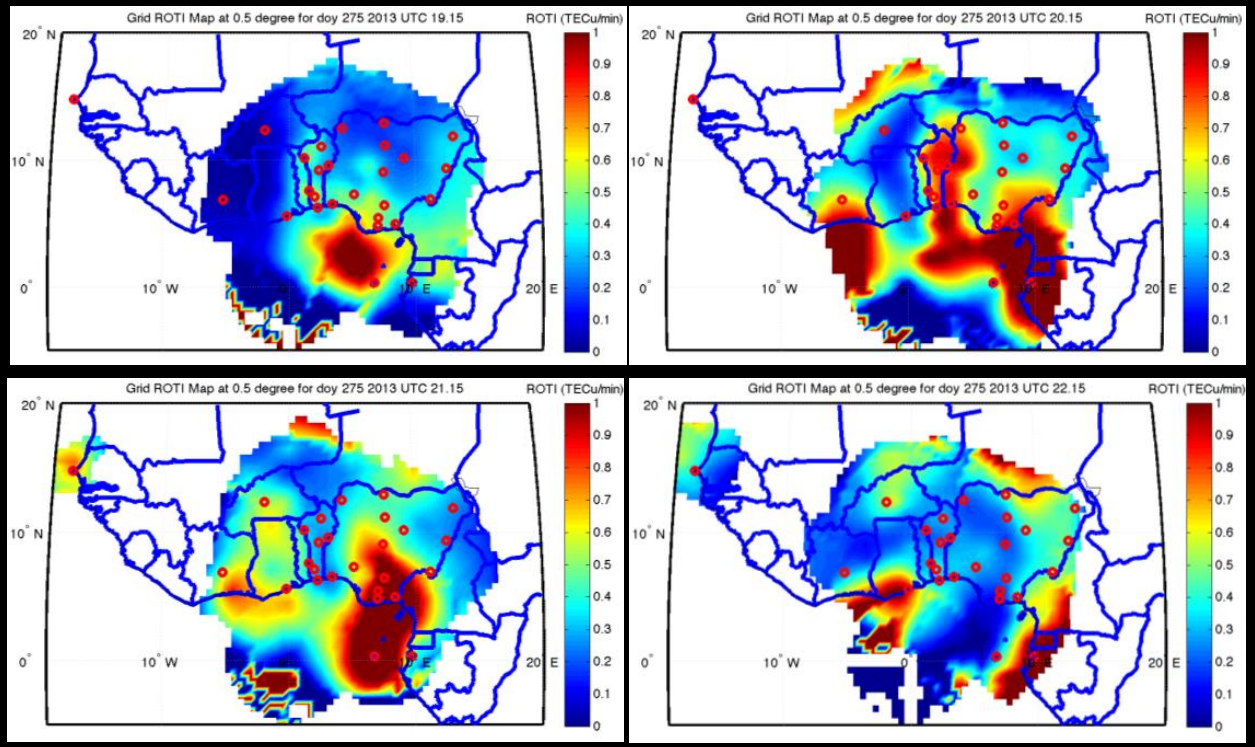


Day 287 year 2013 with inhibitions of irregularities

Test Cases: ROTI maps

After applying an **Ordinary Kriging interpolation** technique, a series of regional grid maps with spacing 0.5 x 0.5 degrees in latitude and longitude have been generated during the hours after the PRE, that is after 18 UT every 5 minutes.

Day 275

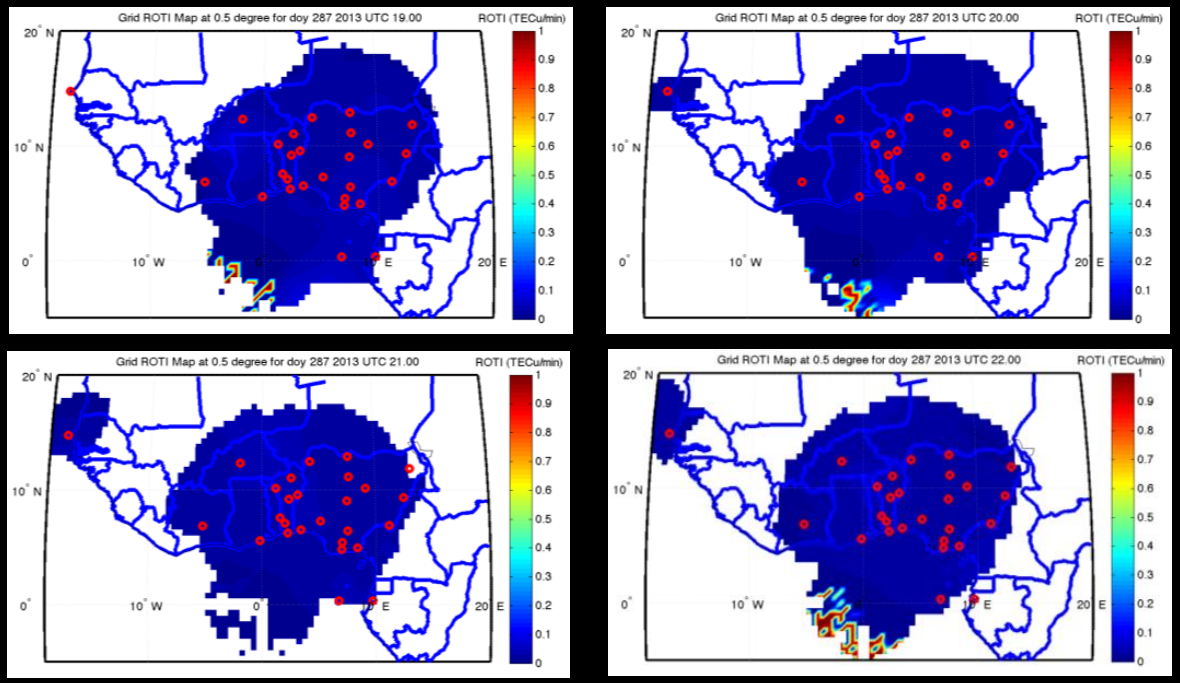


ROTI interpolated Maps for Day 275

Test Cases: ROTI maps

After applying an **Ordinary Kriging interpolation** technique, a series of regional grid maps with spacing 0.5 x 0.5 degrees in latitude and longitude have been generated during the hours after the PRE, that is after 18 UT every 5 minutes.

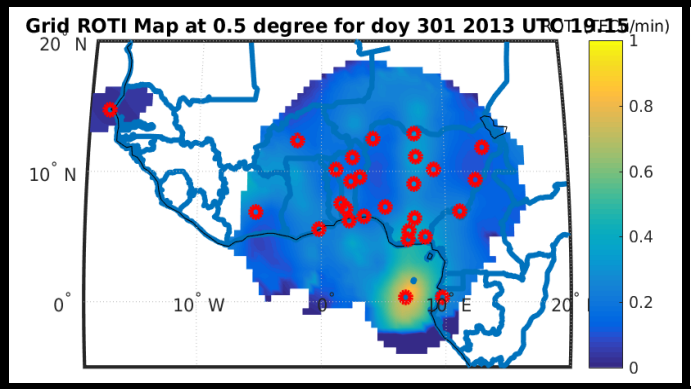
Day 287

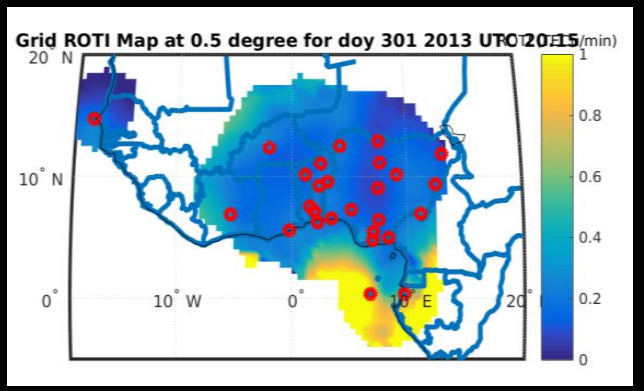


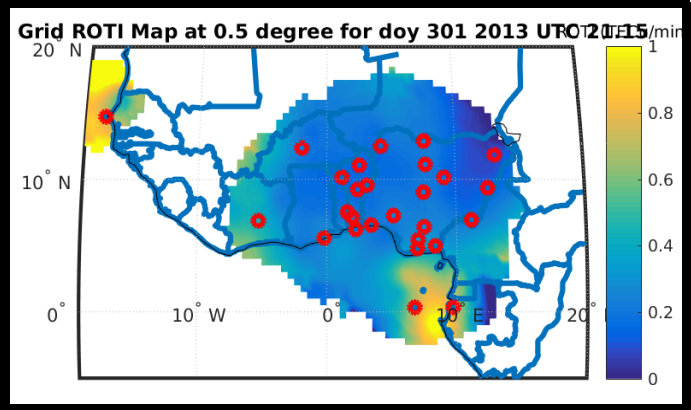
ROTI interpolated Maps for Day 287

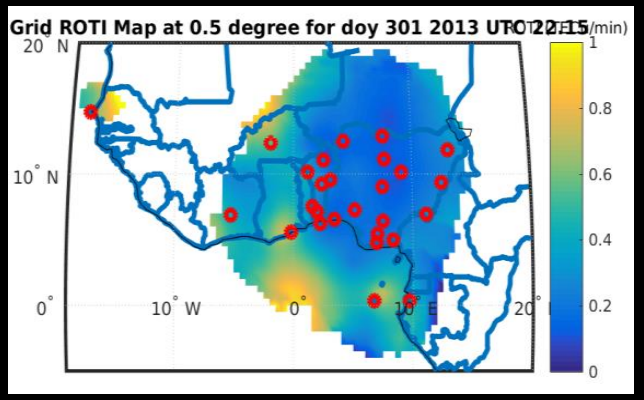
Test Cases: ROTI maps

Day 301 – Quiet Day



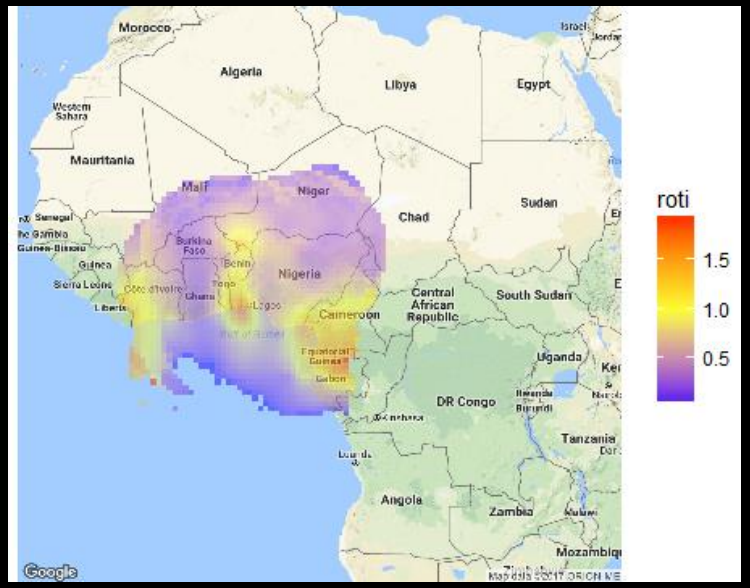






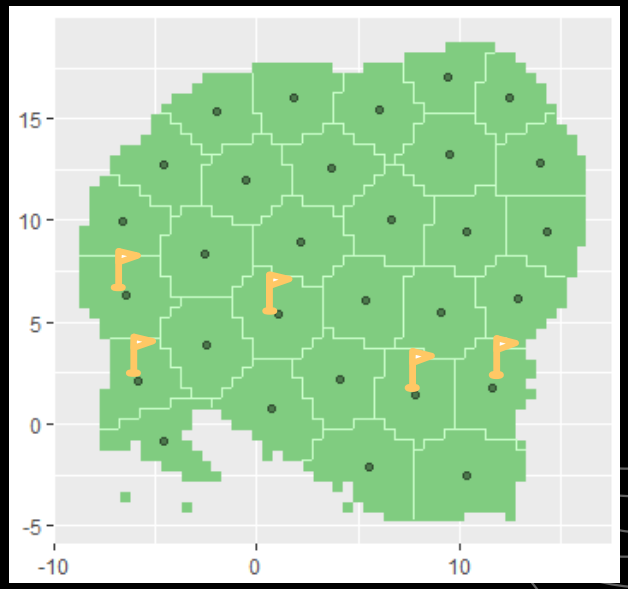
Test Cases: Clustering

Stratification applied to Test cases



k=30

Optimization Sample of the region



Spatial coverage for Day 275 at 20:20 UT with equal area partitioning

	lon	lat	roti
1	1.0406142	5.4264093	0.98796
2	9.0656952	5.4496616	0.89953
3	0.7574102	0.7424731	0.24533
4	13.9909615	12.8552702	0.32832
5	1.8445600	15.9886426	0.28087
6	9.4122007	17.0629056	0.33742
7	12.8660200	6.1328875	0.94803
8	7.8254299	1.4123836	1.10940
9	-2.4998058	3.8854300	0.45060
10	-2.5378407	8.3695419	0.25590
11	-6.6016795	9.9428645	0.77241
12	9.5246104	13.2109367	0.37070
13	-4.6222565	12.7082078	0.35477
14	10.3590898	9.4368107	0.29737
15	6.5936256	10.0758751	0.62692
16	6.0172696	15.4801344	0.54801
17	5.4927833	-2.1228050	0.17332
18	-6.4449116	6.3504329	0.97968
19	11.6189996	1.7535332	1.36880
20	-0.5090778	11.9470749	0.37997
21	4.0738014	2.2208489	0.67802
22	5.3790547	6.0552358	0.53311
23	2.1775499	8.9743649	0.93680
24	10.3294307	-2.5482636	0.55764
25	12.4568628	16.0298895	0.47352
26	3.6786224	12.5873912	0.90425
27	-5.8302737	2.1316645	1.01410
28	-4.5715688	-0.8569324	0.31420
29	14.2820471	9.4893215	0.30181
30	-1.9906776	15.3468051	0.26560

spcosa-package (Walvoort et al., 2009)

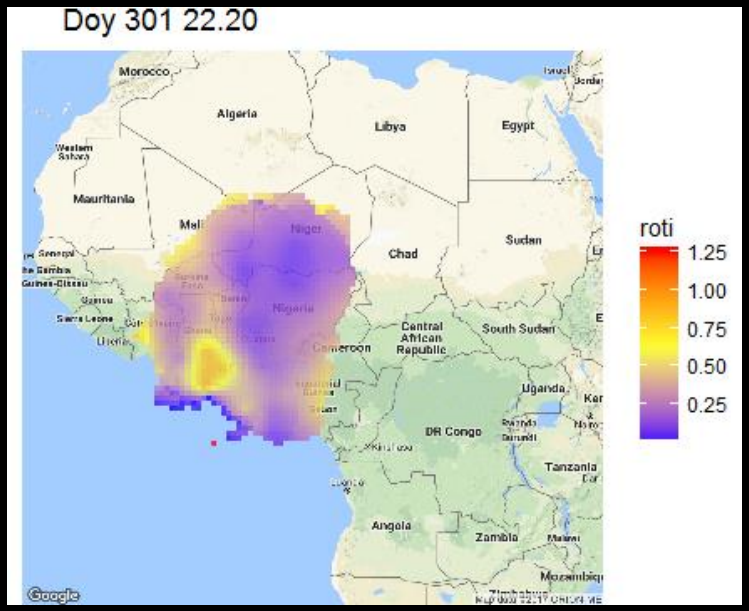
Standard Error: **0.3227168**

0.59 TECU/min

Spatial Mean

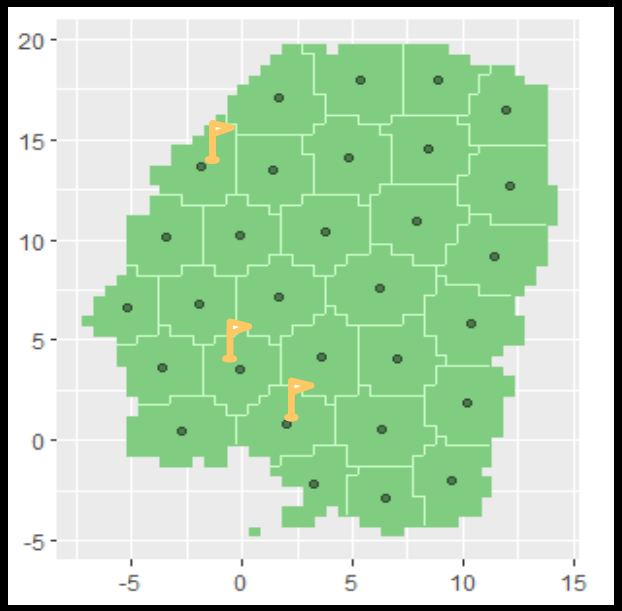
Test Cases: Clustering

Stratification applied to Test cases



k=30

Optimization Sample of the Region



Spatial coverage for Day 301 at 22:20 UT with equal area partitioning

	lon	lat	roti
1	5.33433035	17.9354050	0.251960
2	11.44710797	9.1741088	0.26178
3	10.34243442	5.8323767	0.310780
4	-1.85233973	13.6359440	0.48070
5	-2.71429565	0.4553038	0.25837
6	-0.11120521	10.2096185	0.38294
7	1.43513830	13.4653392	0.216790
8	6.47425093	-2.8970902	0.150690
9	1.64522135	17.1000017	0.341190
10	2.02938754	0.8038183	0.501190
11	2.10049330	12.6976959	0.162650
12	10.18263684	1.8554506	0.431520
13	-0.06530547	3.5103080	0.841880
14	-3.46841862	10.1579548	0.241230
15	7.92117177	10.9543960	0.074431
16	11.95834614	16.4556678	0.239020
17	3.62740587	4.1560713	0.306390
18	6.34823896	0.5981264	0.298500
19	9.45749638	-2.0209020	0.382980
20	-1.95639684	6.8142173	0.305870
21	6.22859991	7.6175812	0.137900
22	4.84957444	14.1012447	0.139580
23	3.26280007	-2.1870801	0.266960
24	-3.61956196	3.6408247	0.331990
25	-5.20300959	6.5937315	0.394250
26	3.74976675	10.4215318	0.137190
27	8.43896970	14.5183123	0.072586
28	7.04080151	4.1116067	0.216580
29	8.87521784	17.9407346	0.220480
30	1.67284558	7.1142810	0.356900

Standard Error: **0.1515899**

0.29 TECU/min
Spatial Mean

04 SUMMARY

SUMMARY

- It is proposed to have a **spatial mean based on ROTI**, as a regional indicator of the presence of irregularities through a sampling process.
- A series of locations and ROTI values of clusters in the mapped area can be reported.
- Regarding the spatial mean, which is based on the average of the values of the centroids, a sufficient number of cases should be computed in order to determine the relevant clusters numbers and thresholds.
- The indicator could be generated in near-real time every 15-20 minutes, taking into account stations availability, time to compute ROTI (every 5 minutes) and computational processing of the clustering.

PROSPECTS

- Use of k-medoids instead of k-means and ‘scientific’ determination of k.
- Use of different clustering techniques (OPTICS)
- Try to avoid spatial interpolation for operational use.

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Specially thanks to spcosa package author, D.J.J. Walvoort.

References

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Walvoort, D.J.J., Brus, D.J., de Gruijter, J.J.,2009. spcosa: Spatial coverage sampling and random sampling from compact geographical strata. R package version 0.2-1 /http://cran.r-project.org/package=spcosaS

THANKS

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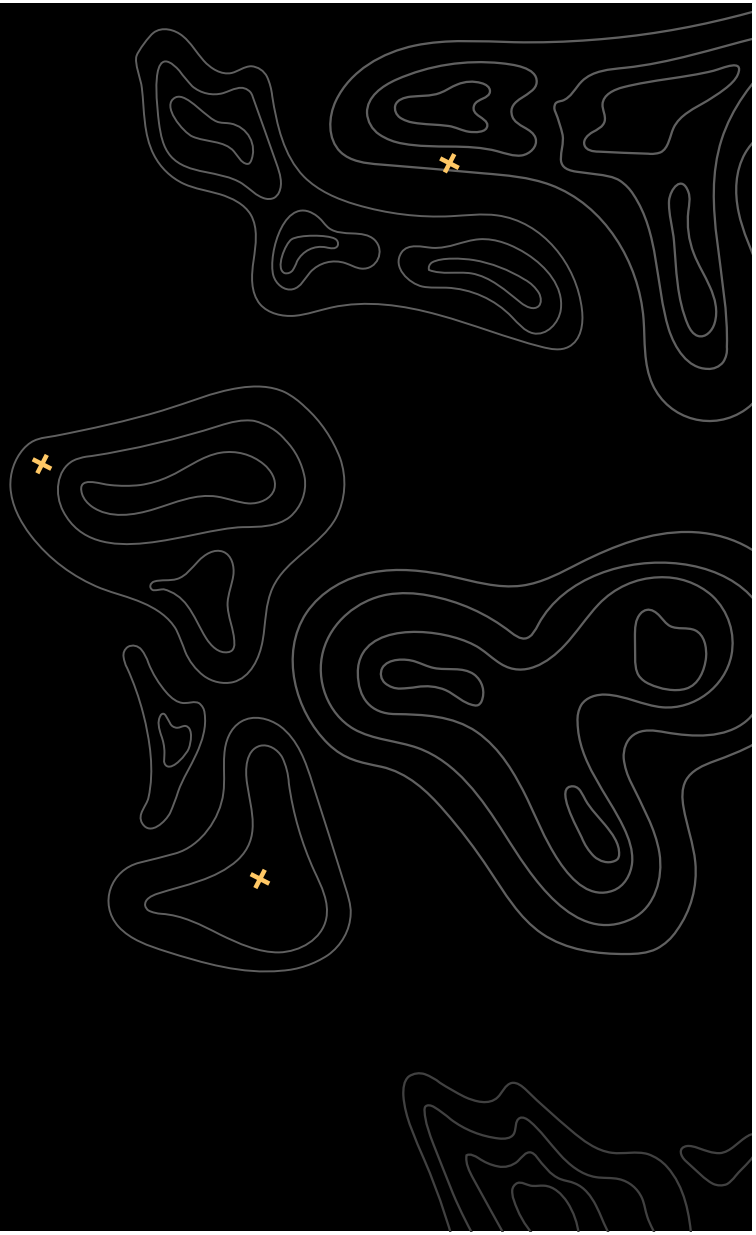

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