UNIVERSITY OF TURIN
Doctoral School of Sciences and Innovative Technologies
Ph. D. program in Earth Science - XXIX cycle

Urban flooding forecasting with weather radar and dense rain gauges network

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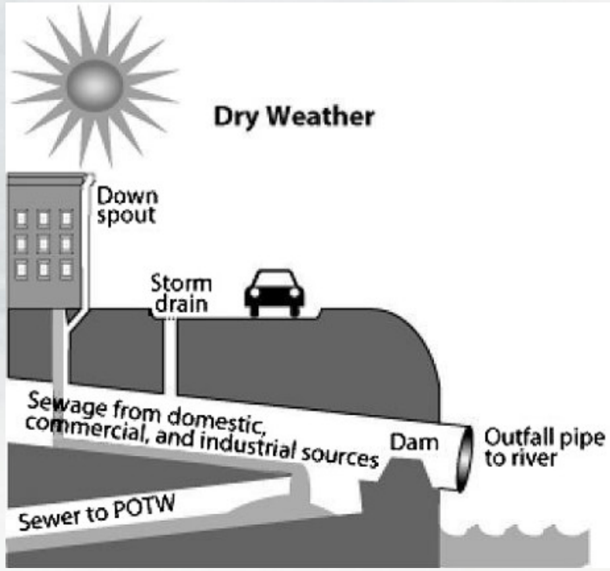
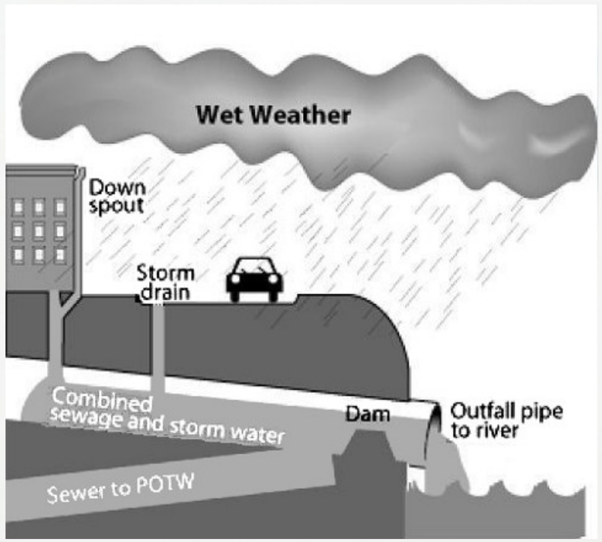
Introduction

- On dry weather all works perfectly
- On wet weather... it depends!
  - Normally, long-duration light rains are drained in time by urban sewers and do not pose a threat
  - Extreme rainfall events can overwhelm the capacity of drainage systems causing
    - backup through sewer pipes, toilets and sinks into buildings
    - overflow from water bodies such as rivers and lakes
    - seepage through building walls and floors
    - accumulation of water on properties
    - …
  - This is known as **urban flooding**





Drainage systems are not always adequate

...they can fail!

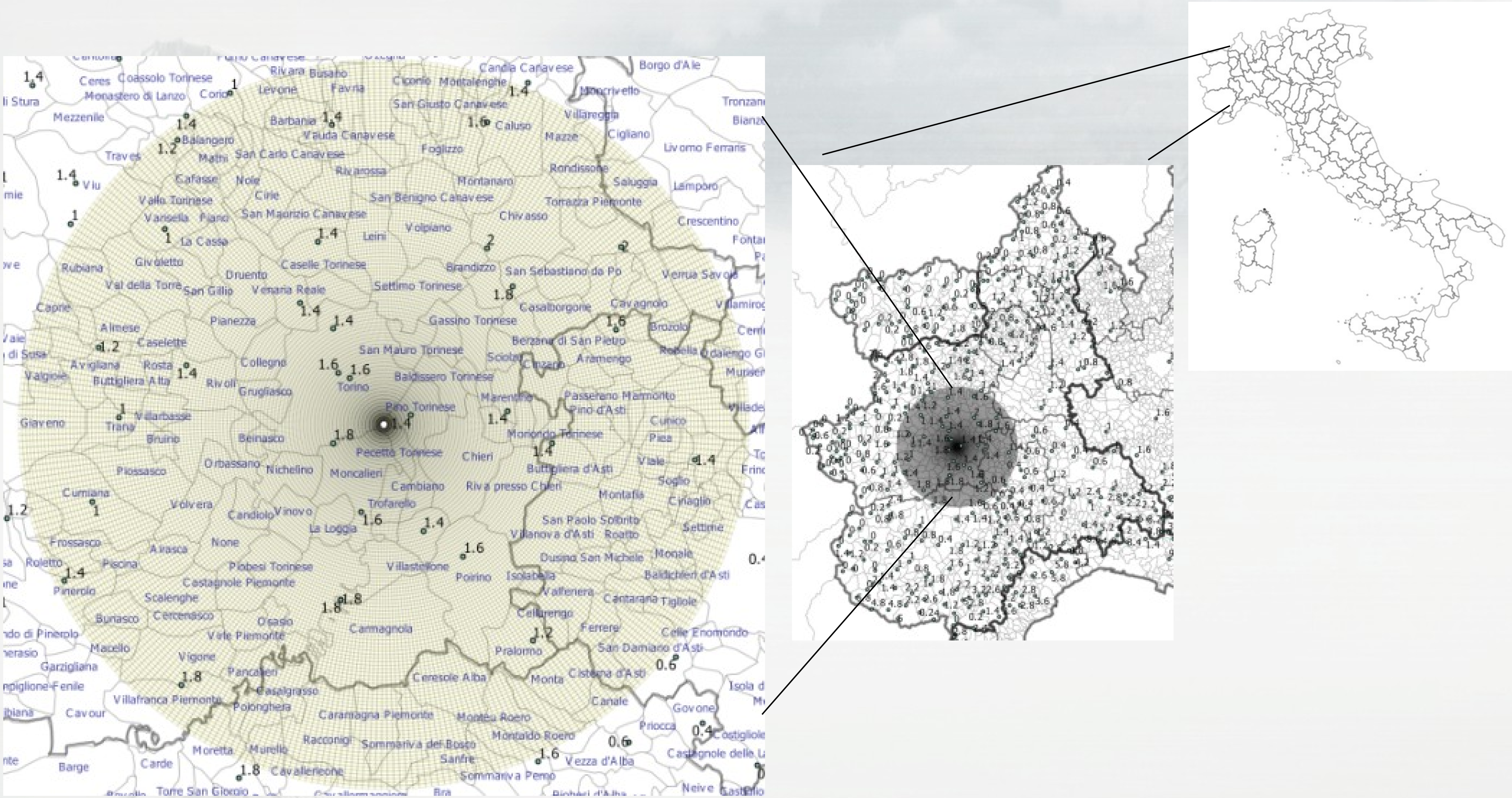
How can I be prepared to this?

- Monitoring, prediction and prevention!

Objectives of this study

- Predict urban flooding events using radar data
- After clutter removal and other cleaning operations, radar is using a traditional climatological Z-R relation to estimate rainfall intensity
  - Gives average results on the whole territory
  - It is not so accurate for small zones
- We are going to optimize data for a specific study area, to obtain better evaluations and, maybe, accurate forecasts
  - Comparing information with ground measurements given by a dense rain gauges network
    - to improve its accuracy
    - to reduce uncertainties and biases
  - Test case based on some rainfall events (both convective and advective) on the metropolitan area of Turin (Piedmont, NW Italy)
  - Analysis on hourly rain data
  - Work in progress

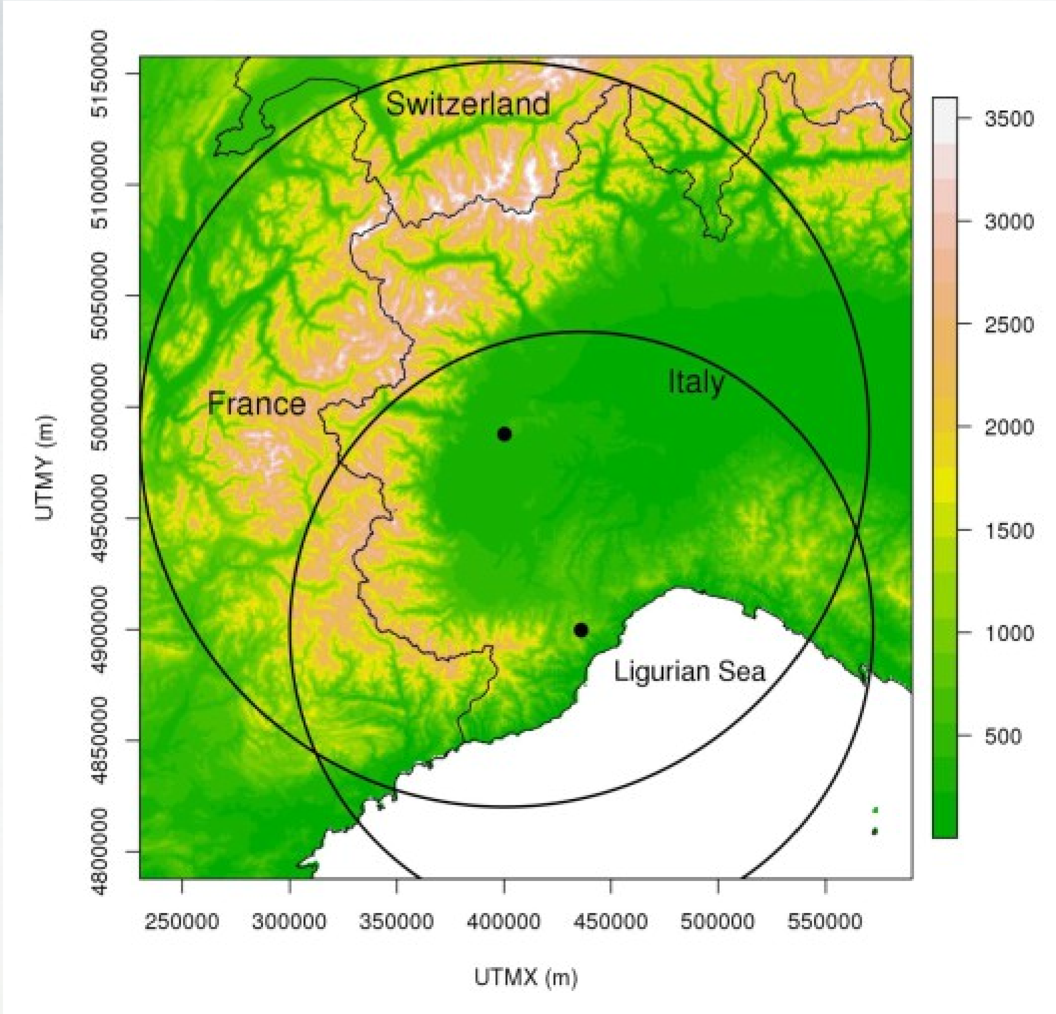
Study area



Ceres
Coassolo Torinese
Monastero di Lanzo
Corio
Rivara
Busano
Levone
Favria
Candia Canavese
Borgo d'Ale
Ciconio
Montalenghe
San Giusto Canavese
Moncrivello
Mezzenile
Barbania
Caluso
Villareggia
Balangero
Vauda Canavese
Mazze
Cigliano
Traves
Mathi
San Carlo Canavese
Foglizzo
Livorno Ferraris
Viu
Rivarossa
Rondissone
Cafasse
Nole
Montanaro
Saluggia
Lamporo
Vallo Torinese
Cirie
San Benigno Canavese
Torrazza Piemonte
Varisella
Fiano
San Maurizio Canavese
Chivasso
Crescentino
La Cassa
Volpiano
Leini
Rubiana
Givoletto
Caselle Torinese
Brandizzo
San Sebastiano da Po
Verrua Savoia
Druento
Val della Torre
San Gillio
Venaria Reale
Settimo Torinese
Casalborgone
Cavagnolo
Caprie
Almese
Pianezza
Gassino Torinese
Brozolo
Caselette
Berzano di San Pietro
San Mauro Torinese
Avigliana
Rosta
Collegno
Sciolze
Aramengo
Valgioie
Buttigliera Alta
Rivoli
Grugliasco
Torino
Baldissero Torinese
Marentino
Passerano Marmorito
Villarbasse
Pino Torinese
Pino d'Asti
Giaveno
Trana
Bruino
Beinasco
Moriondo Torinese
Cunico
Piea
Orbassano
Nichelino
Pecetto Torinese
Chieri
Piossasco
Moncalieri
Buttigliera d'Asti
Viale
Soglio
Cumiana
Cambiano
Riva presso Chieri
Montafia
Cinaglio
Volvera
Candiolo
Vinovo
Trofarello
San Paolo Solbrito
Settime
La Loggia
Villanova d'Asti
Roatto
Frossasco
Airasca
None
Dusino San Michele
Monale
Roletto
Piscina
Piobesi Torinese
Villastellone
Poirino
Isolabella
Baldichieri d'Asti
Pinerolo
Castagnole Piemonte
Valfenera
Cantarana
Tigliole
Scalenghe
Buriasco
Cercenasco
Osasio
Carmagnola
Cellarengo
Ferrere
Celle Enomondo
Vigone
Pralormo
San Damiano d'Asti
Macello
Garzigliana
Pancalieri
Ceresole Alba
Monta
Cisterna d'Asti
Casalgrasso
Villafranca Piemonte
Polonghera
Canale
Govone
Cavour
Caramagna Piemonte
Monteu Roero
Priocca
Moretta
Murello
Racconigi
Sommariva del Bosco
Montaldo Roero
Barge
Cardè
Sanfre
Vezza d'Alba
Cavallerleone
Sommariva Perno
Torre San Giorgio
Neive

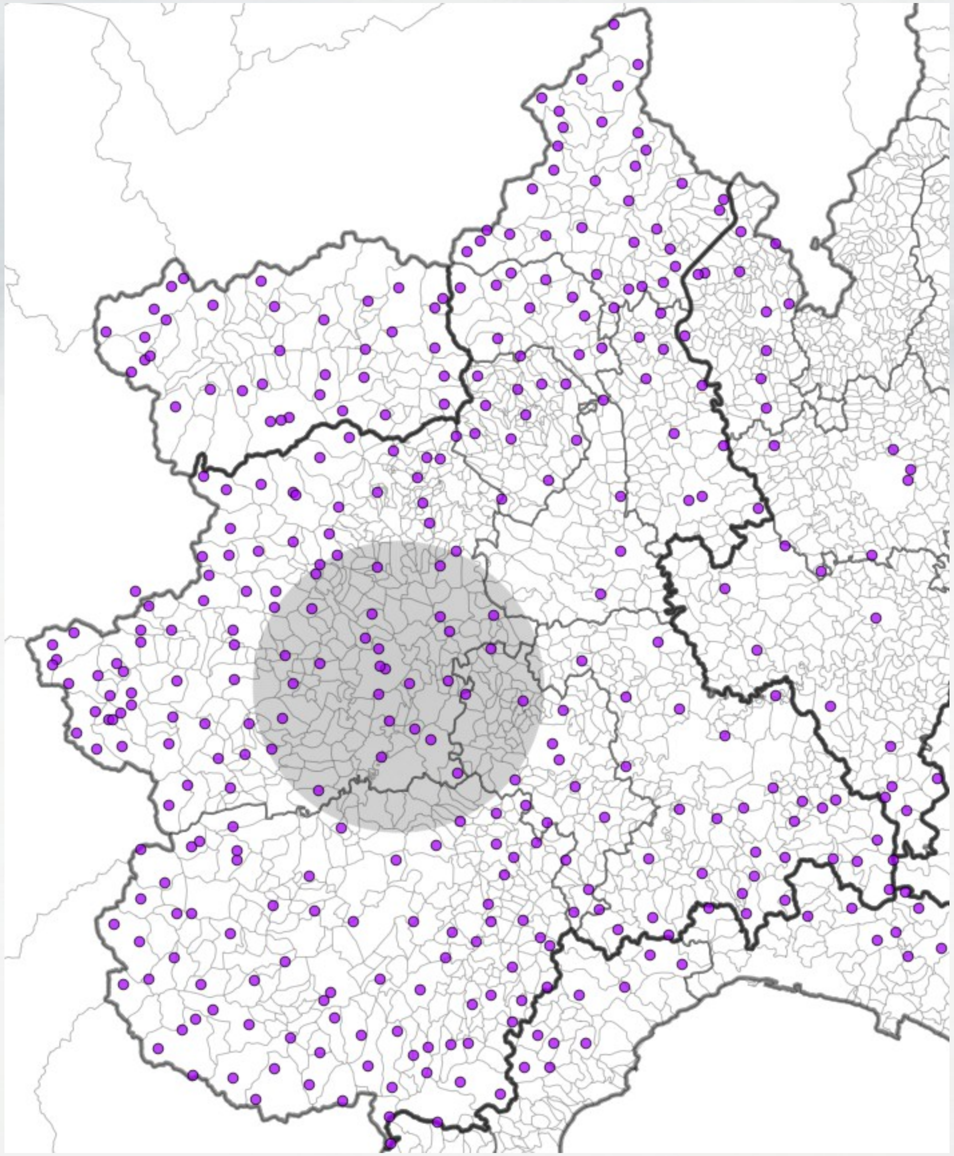
Weather radars

- Two GPM 250 C-band polarimetric Doppler radar are in the neighborhood
  - Mount Settepani (Liguria region, Italy), 1387 m a.s.l.
  - Bric della Croce (Piedmont region, Italy), 736 m a.s.l.
- Part of the surveillance network of the National Civil Protection
- Operated by the Regional Agencies for Environment Protection (ARPA) of Piedmont and Liguria

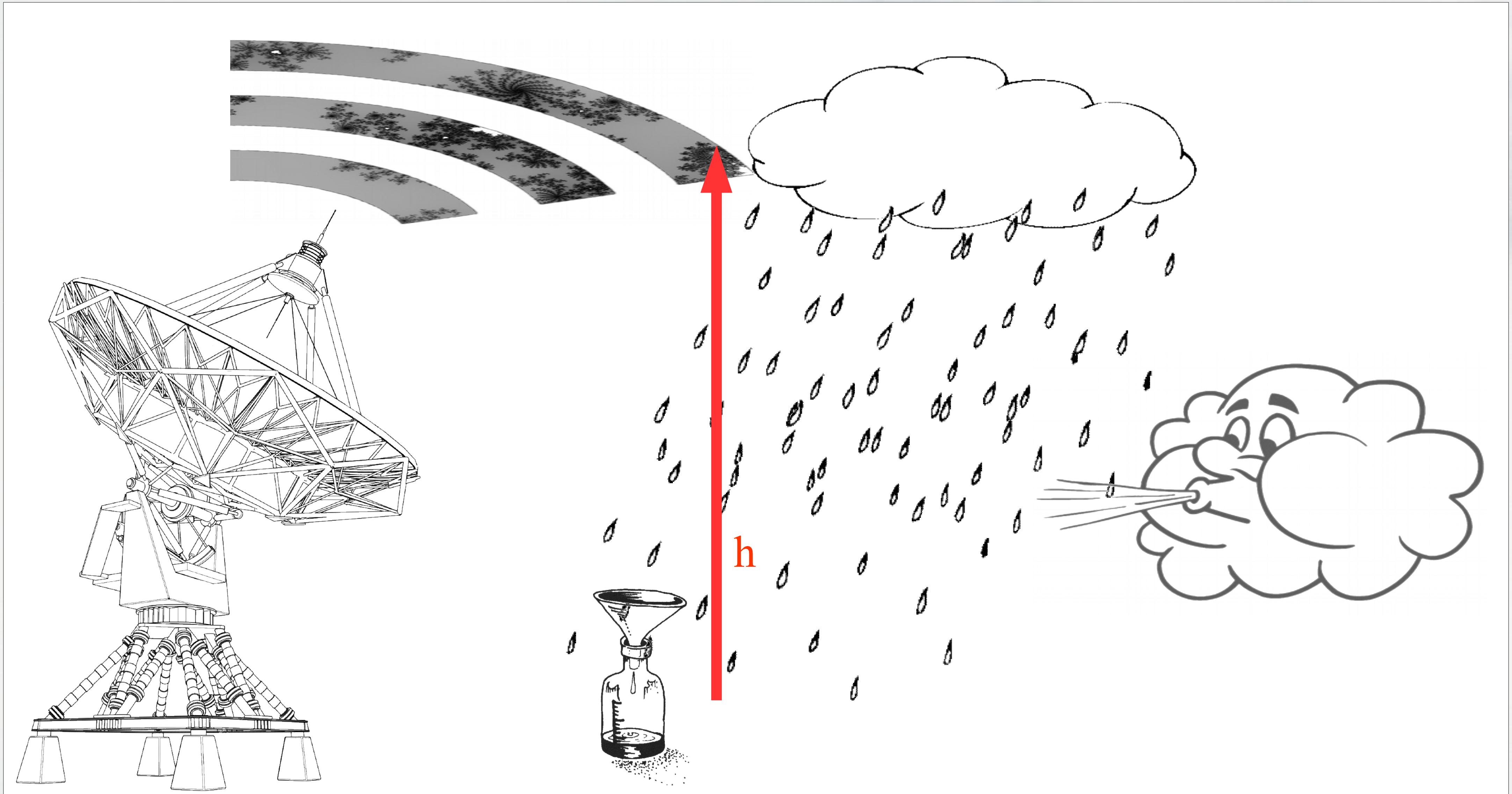


Rain gauges network

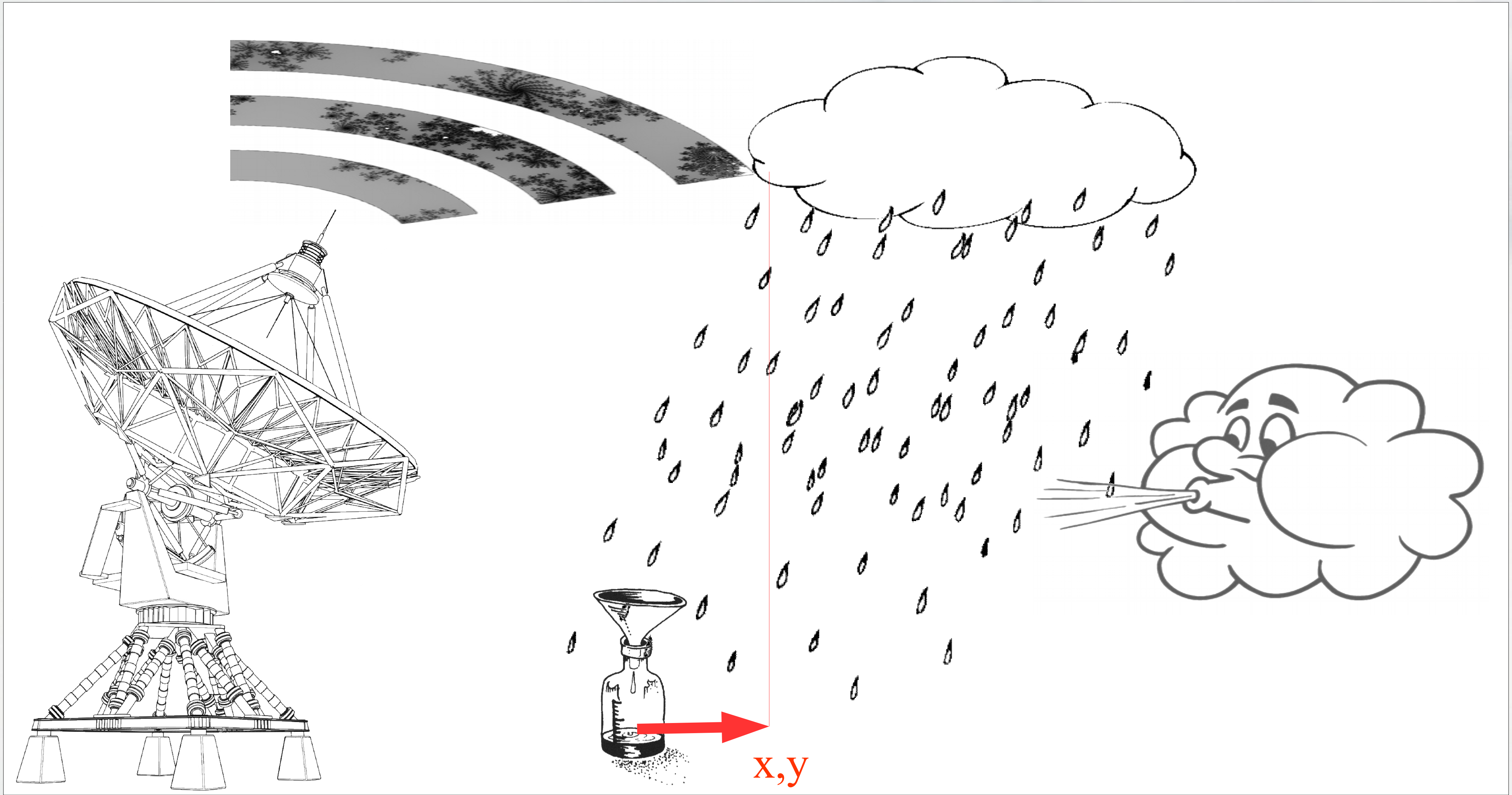
- Dense network of different tipping bucket rain gauges, owned by a single organization
  - More than 350 gauges in a 25.000 Km^2 territory
  - 35 of them in the 3.800 Km^2 of the neighborhood of the metropolitan area of Turin
- Part of the surveillance network of the National Civil Protection
- Used by the Regional Agency for Environment Protection (ARPA) of Piedmont



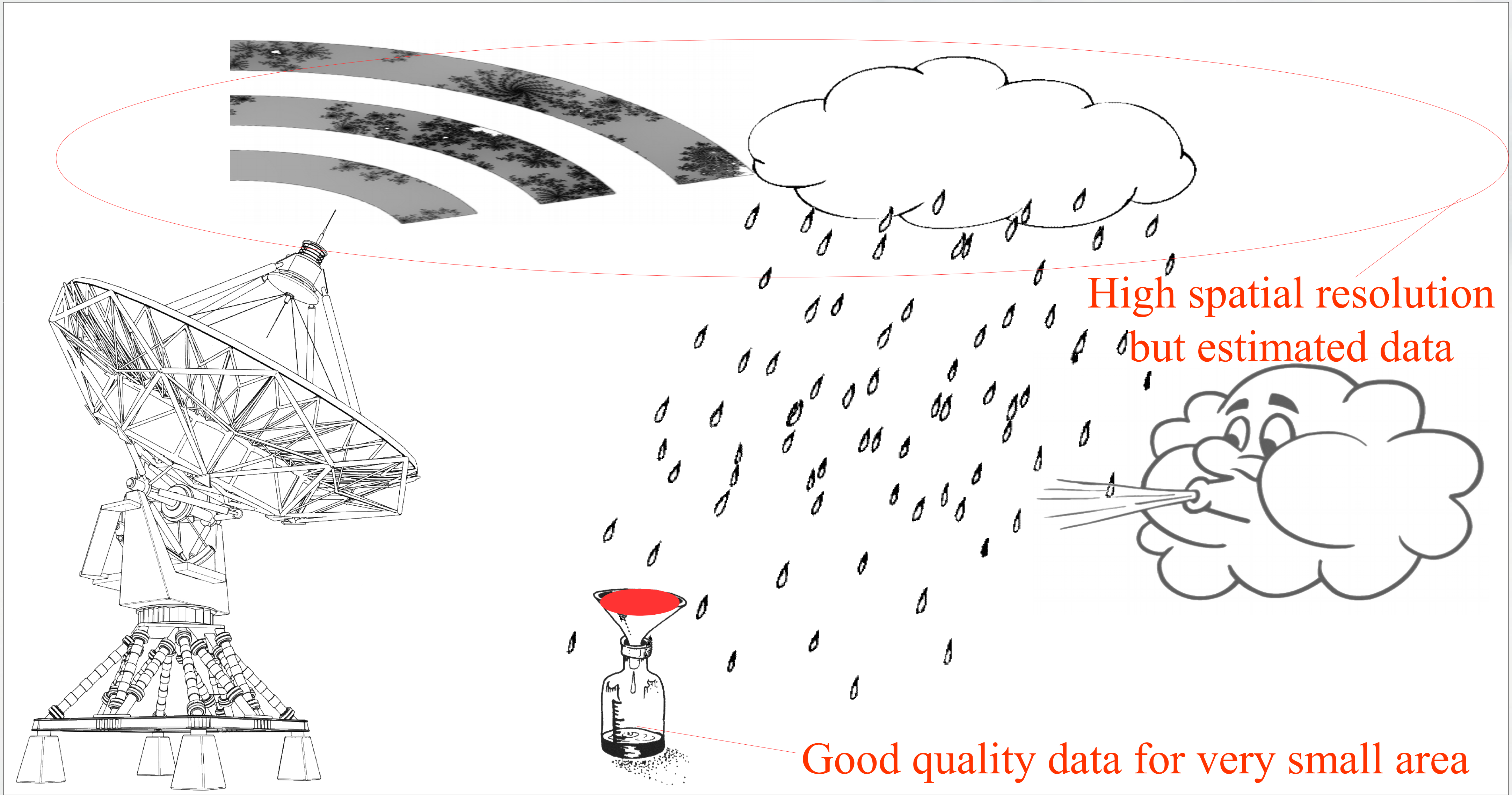
Issues



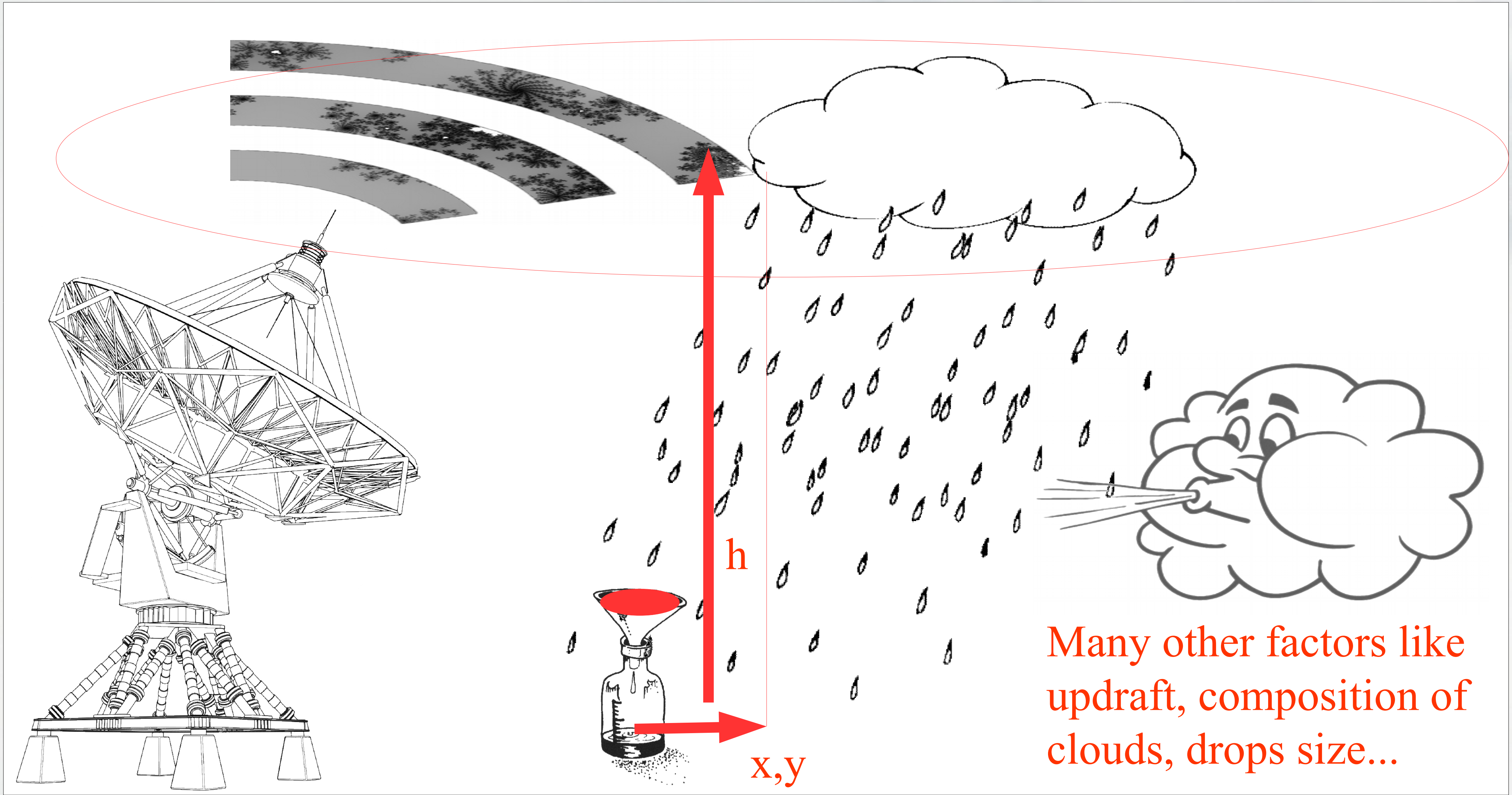
Issues



Issues


High spatial resolution
but estimated data
Good quality data for very small area

Issues


h
x,y
Many other factors like updraft, composition of clouds, drops size...

Approach

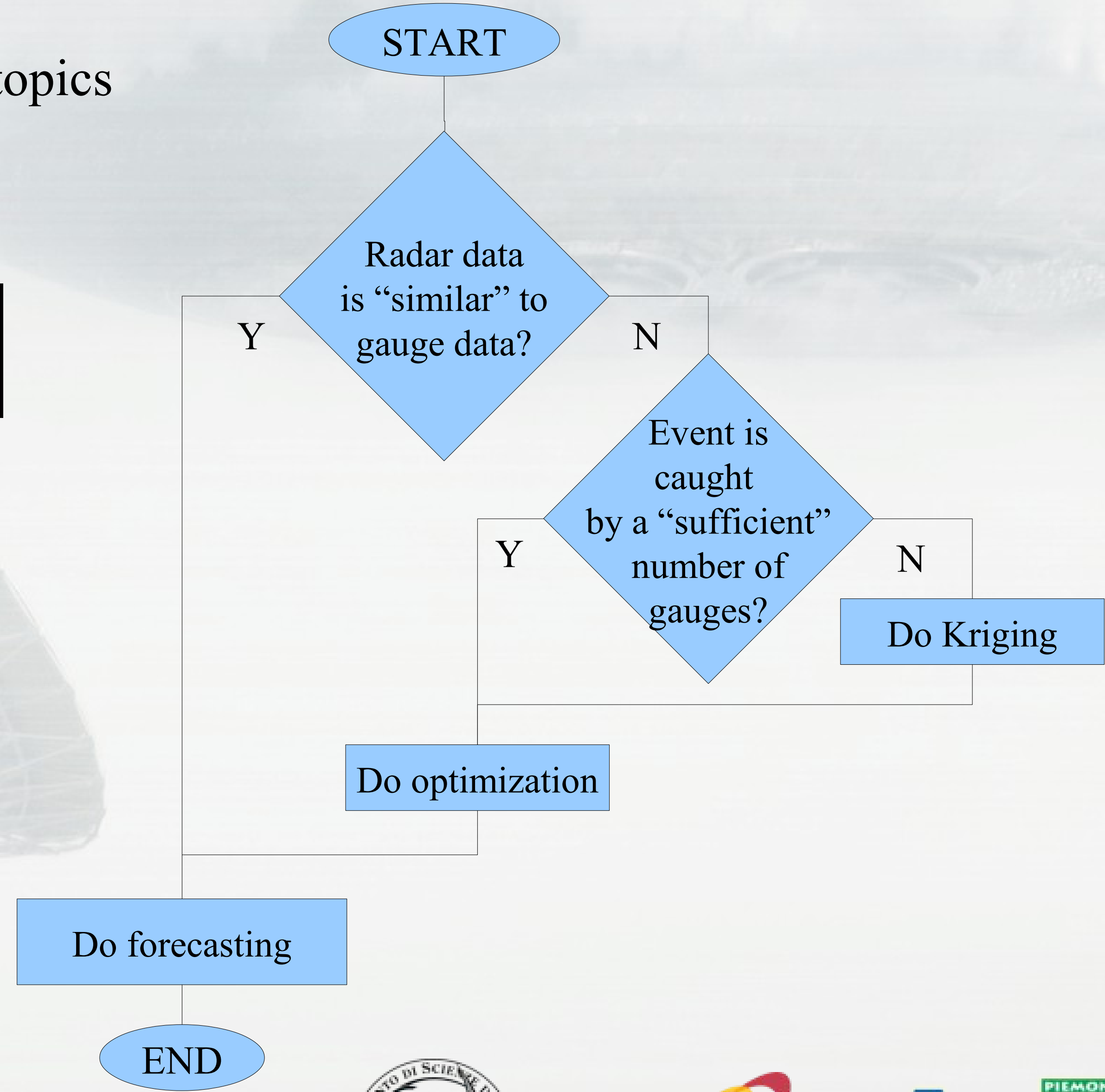
We need a low time-consuming algorithm if we want to do predictions in near-real time

- Everything should be made as simple as possible, but not simpler
  - *Albert Einstein*
- Perfection is achieved, not when there is nothing more to add, but when there is nothing left to take away
  - *Antoine de Saint-Exupéry*

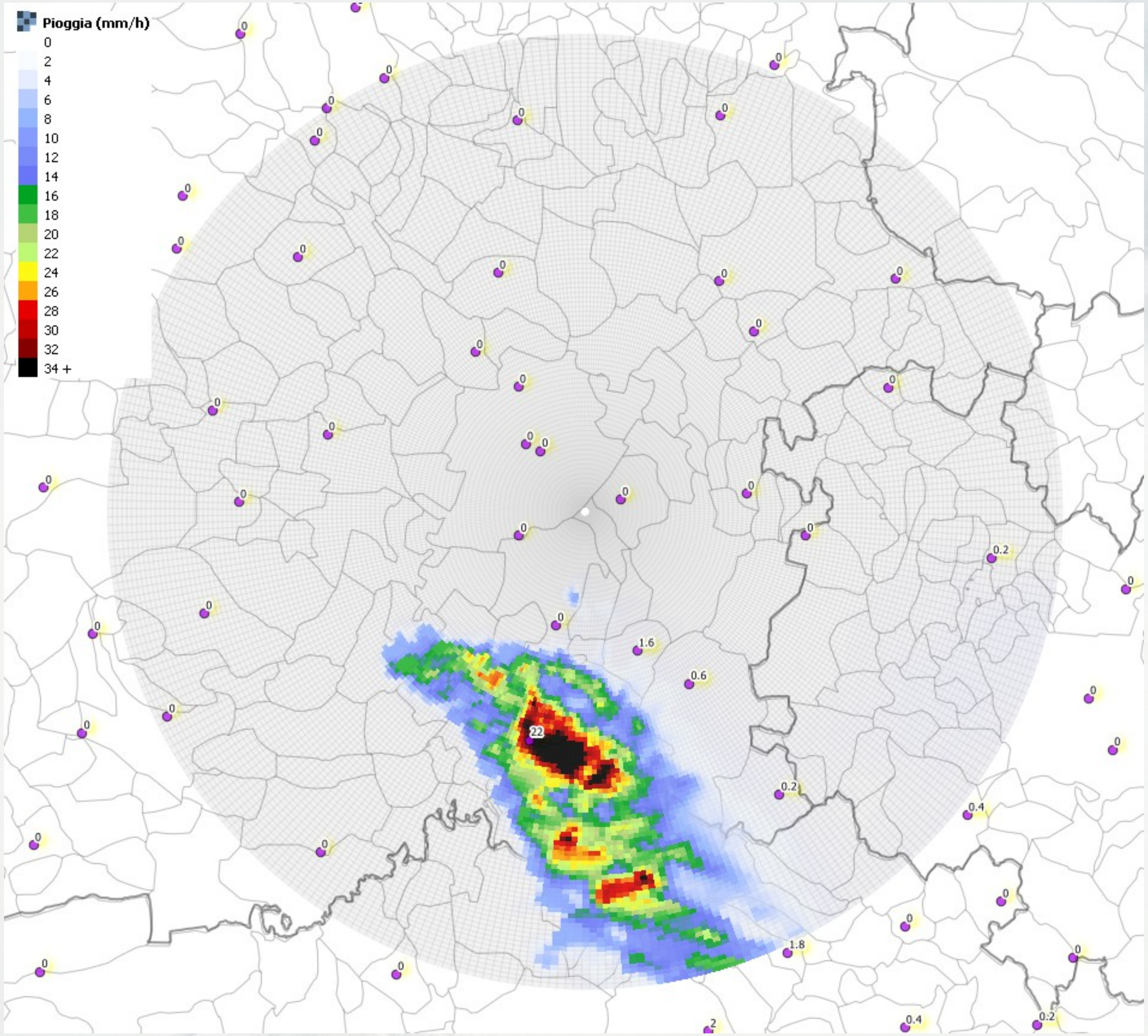
How we proceed?

- A typical IT approach for complex topics
  - Problem analysis
  - Data analysis
  - Divide et impera
  - Always remember:

- So, three main phases:
  - Kriging
  - optimization
  - forecasting/nowcasting
    (early stage/future work)

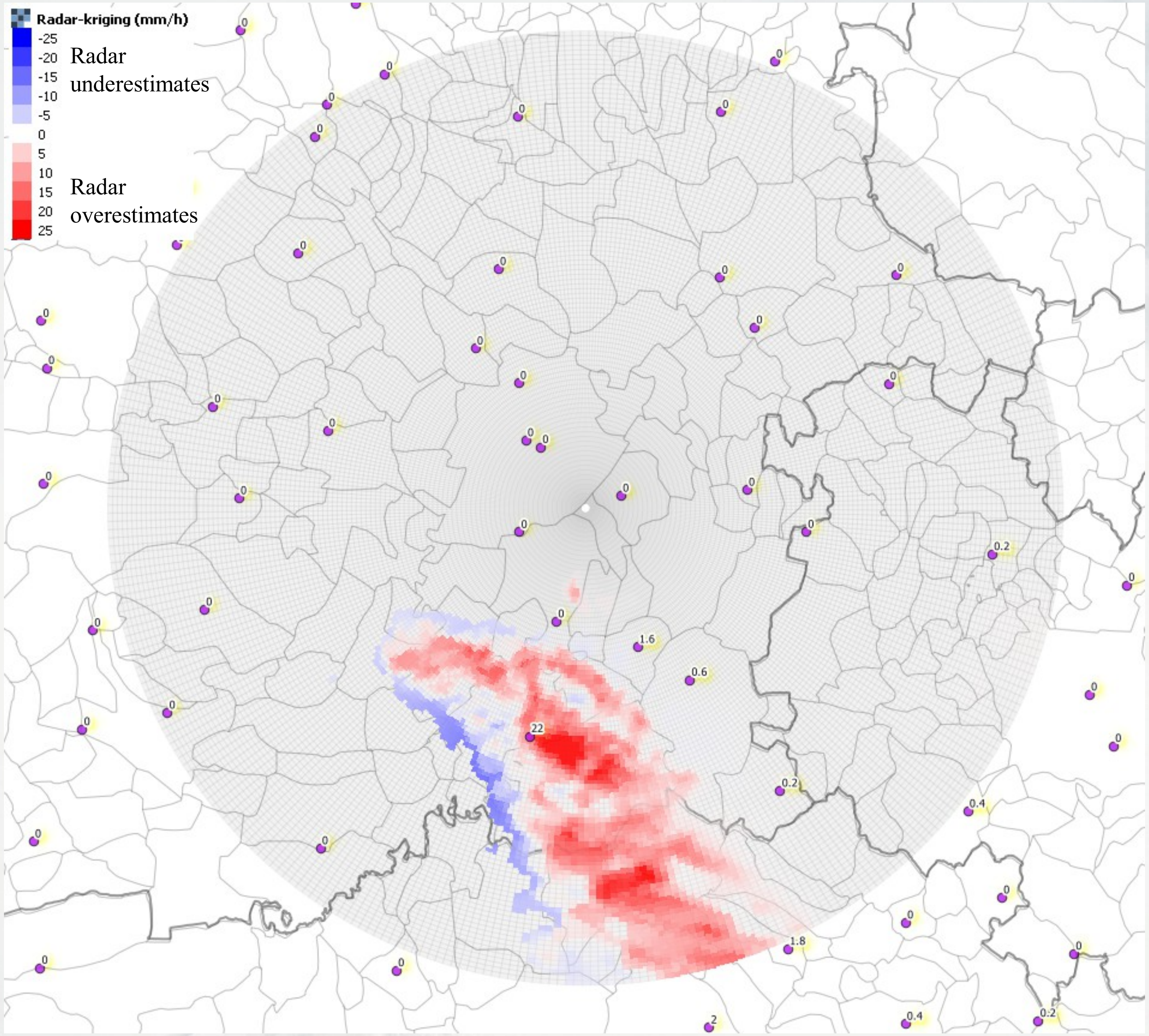


Why Kriging could be necessary?



- Example: extreme rainfall event near Turin on 2014-07-08
- Event caught by a single rain gauge
- Nearly impossible to represent with a single information
- Requires spatialization!
  - Helps in obtaining ground information in “every” point, even where there isn't a gauge
  - Very imprecise
  - Use it only if there are no other solutions

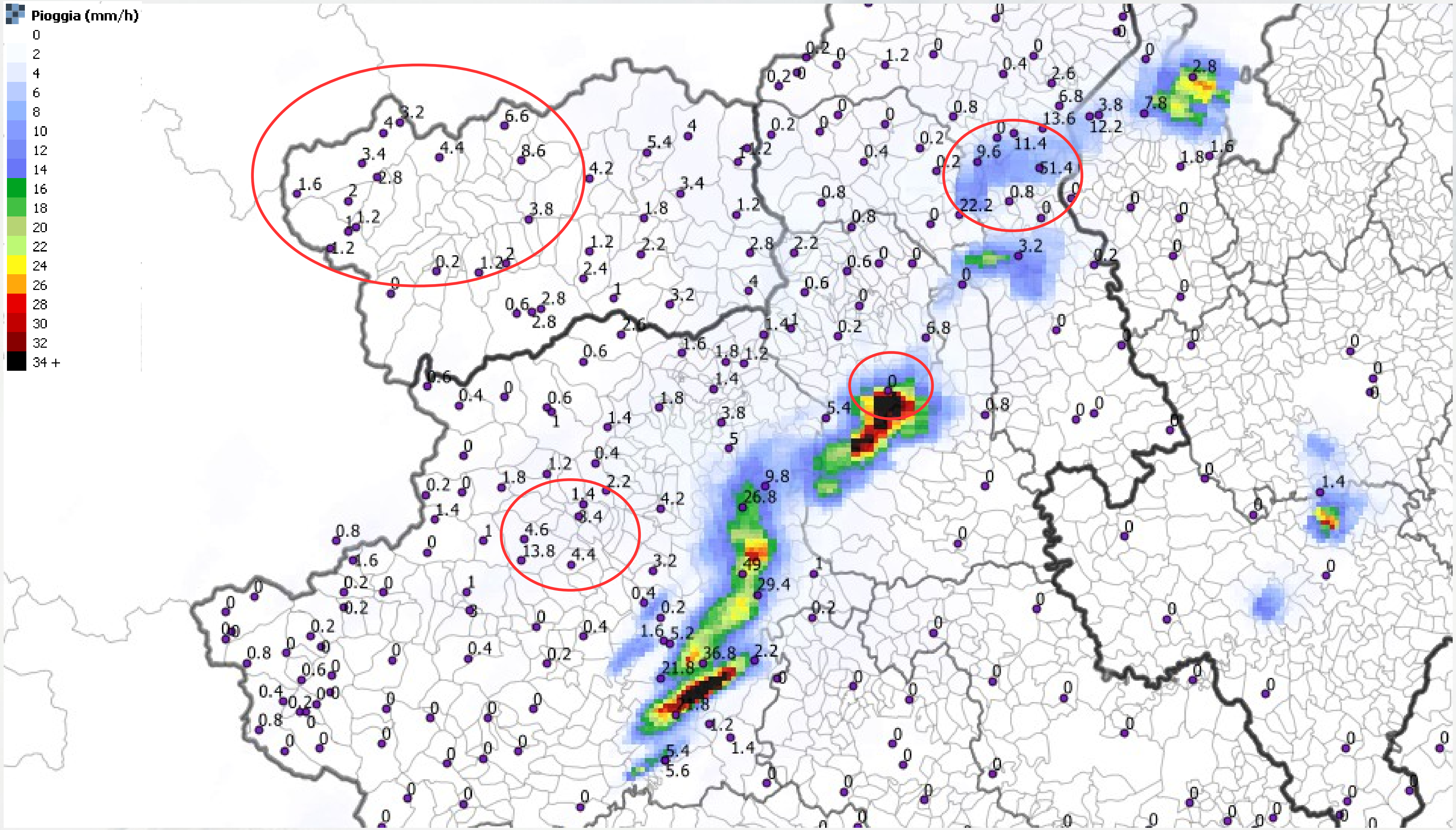
What Kriging says...



… and not only Kriging

- Subtracting Kriging information from radar data
- This always happens, even if not using Kriging but taking only real rain gauges points!
- Data cannot be used "as is"

(In)coherency between radar and gauges data

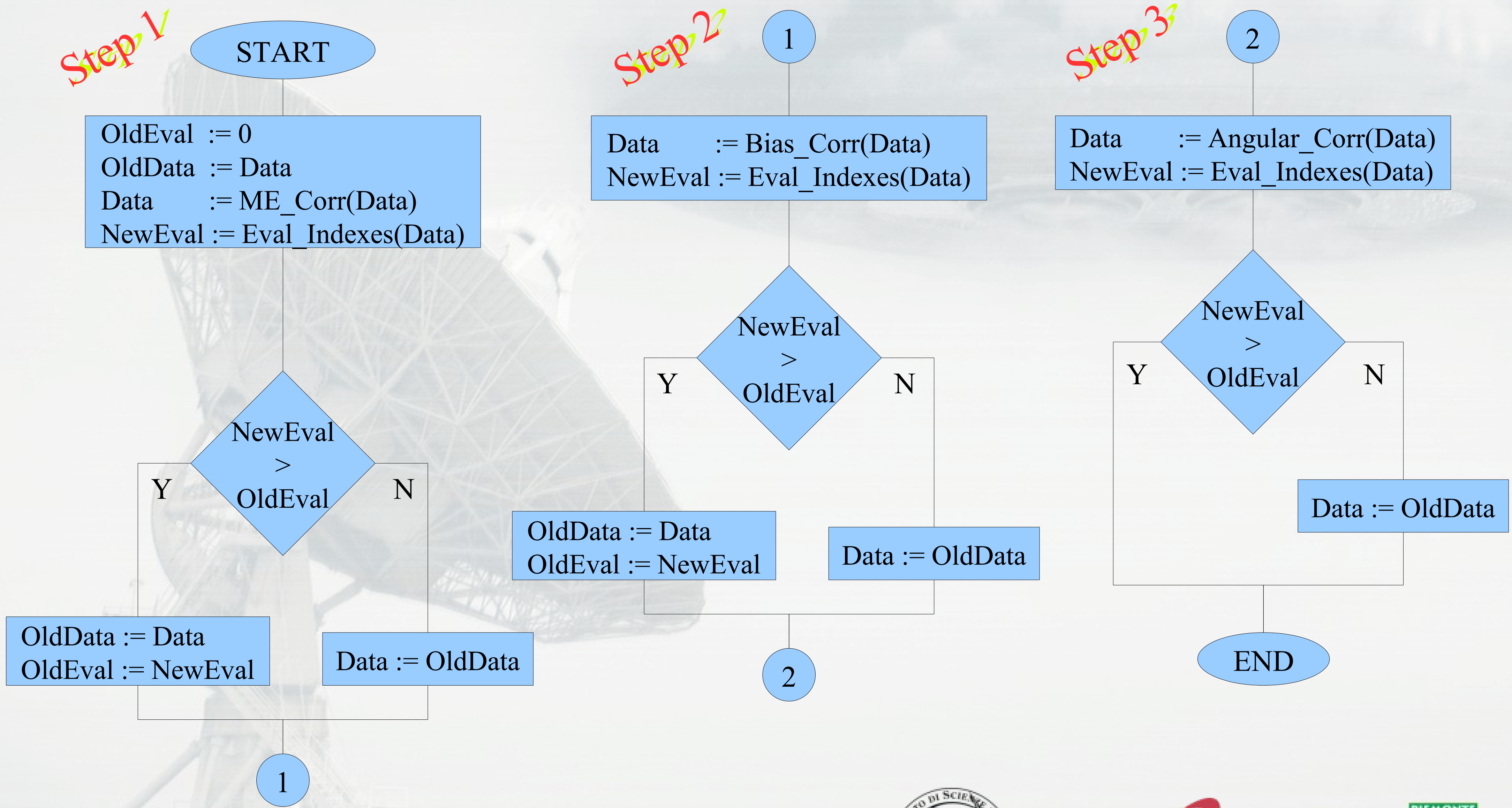


Rainfall event on Piedmont, 2014-07-28

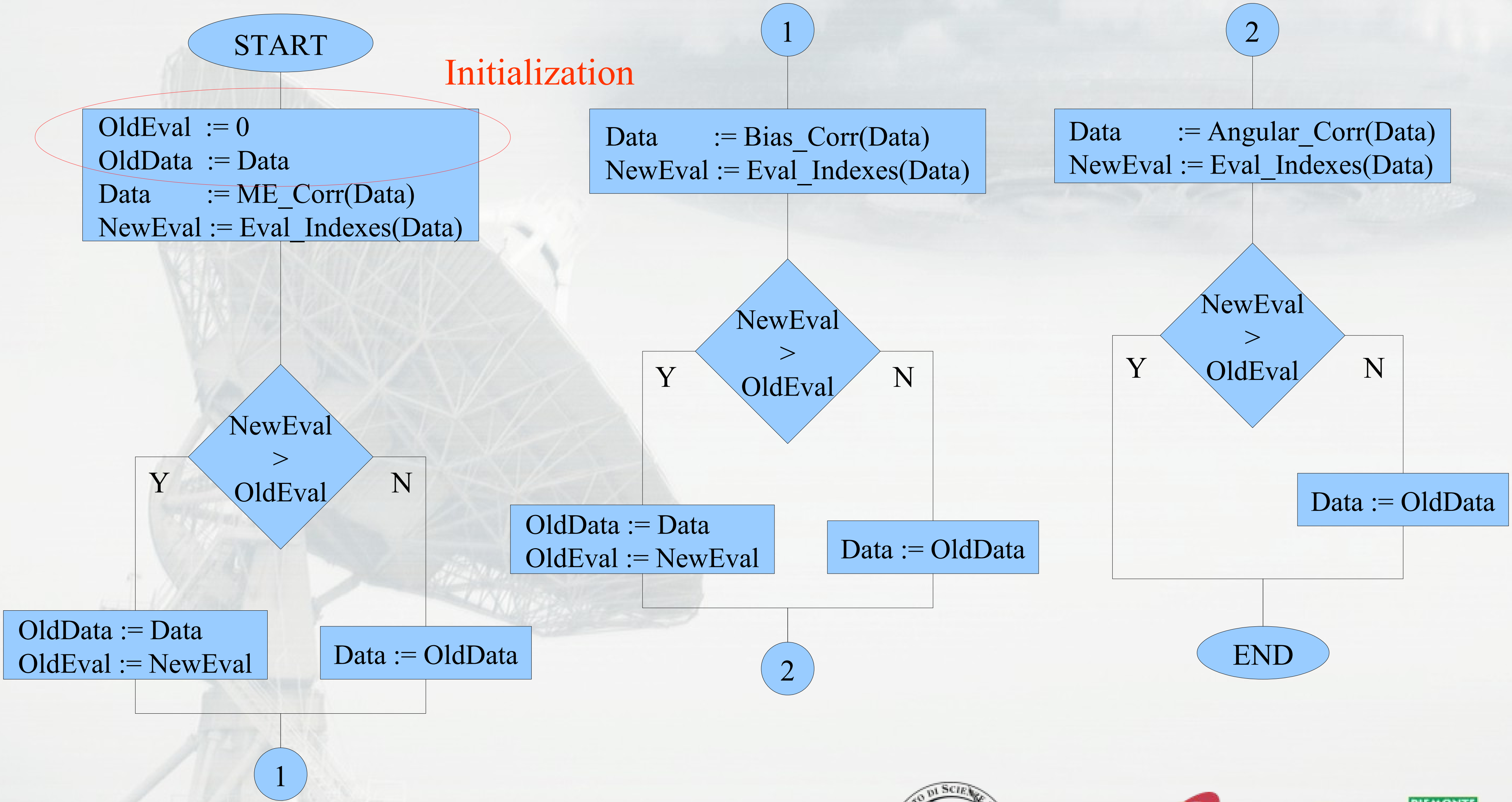
So, why optimization?

Reduce errors

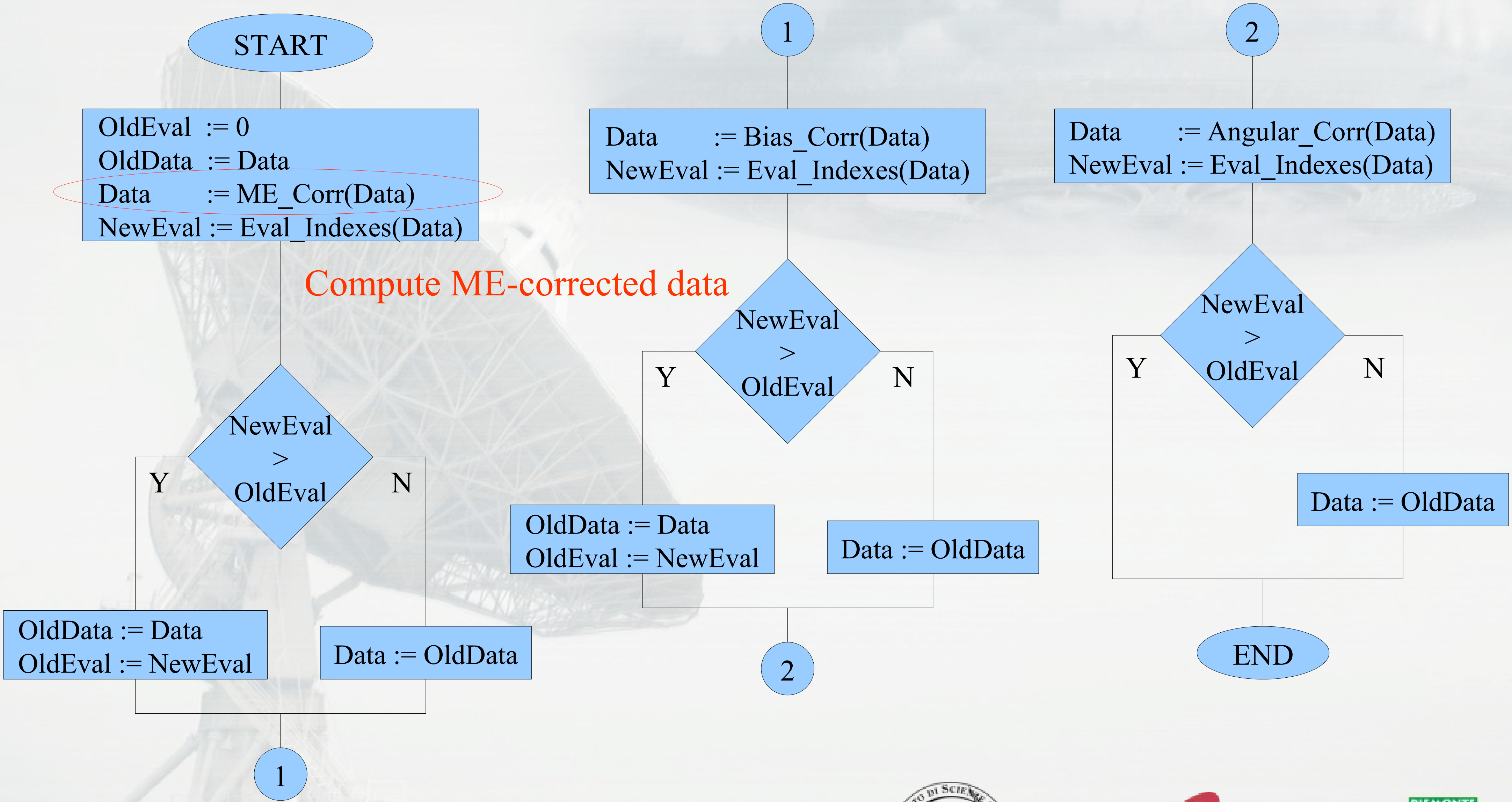
Optimization algorithm definition



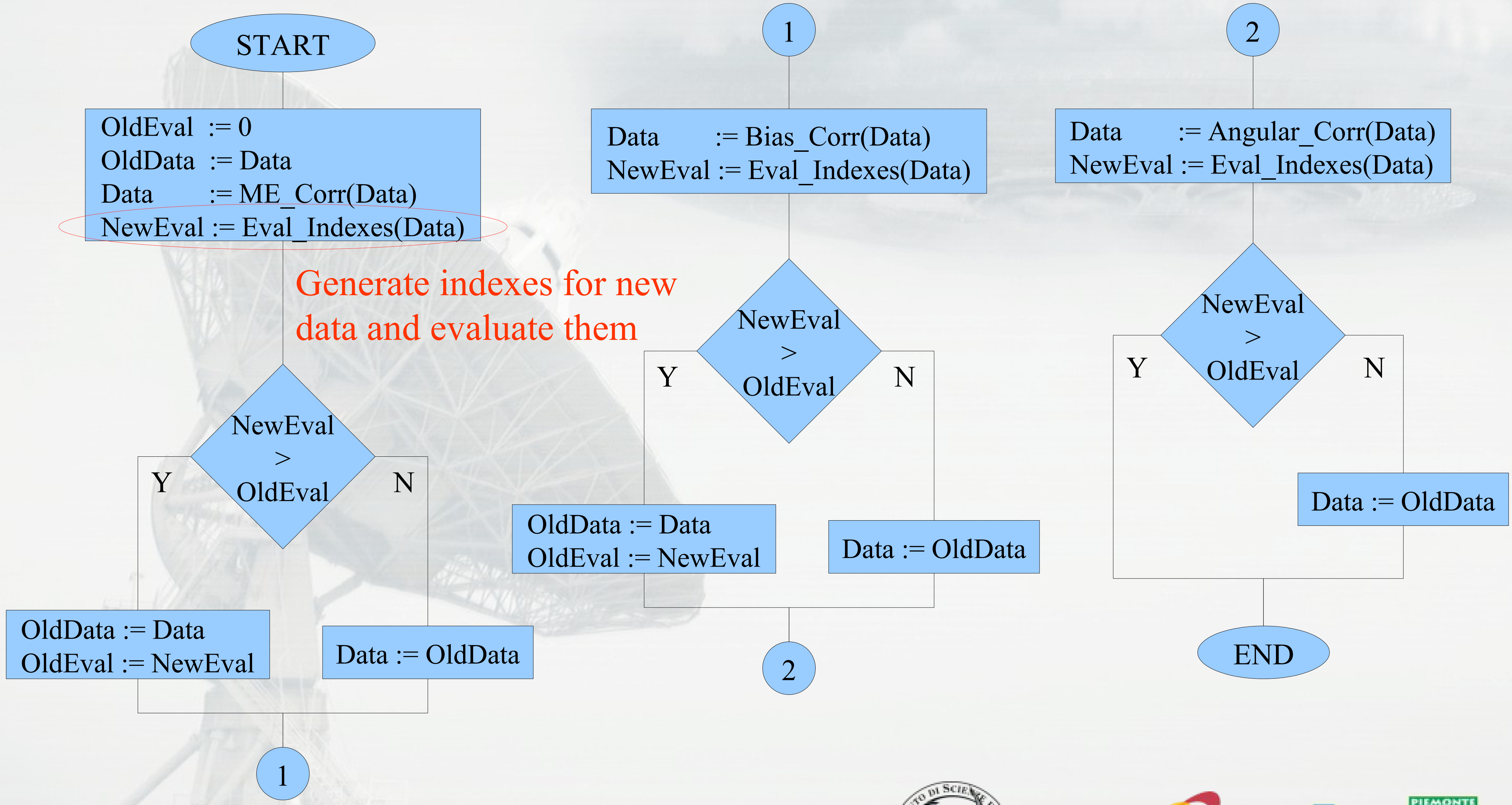
Algorithm explaination



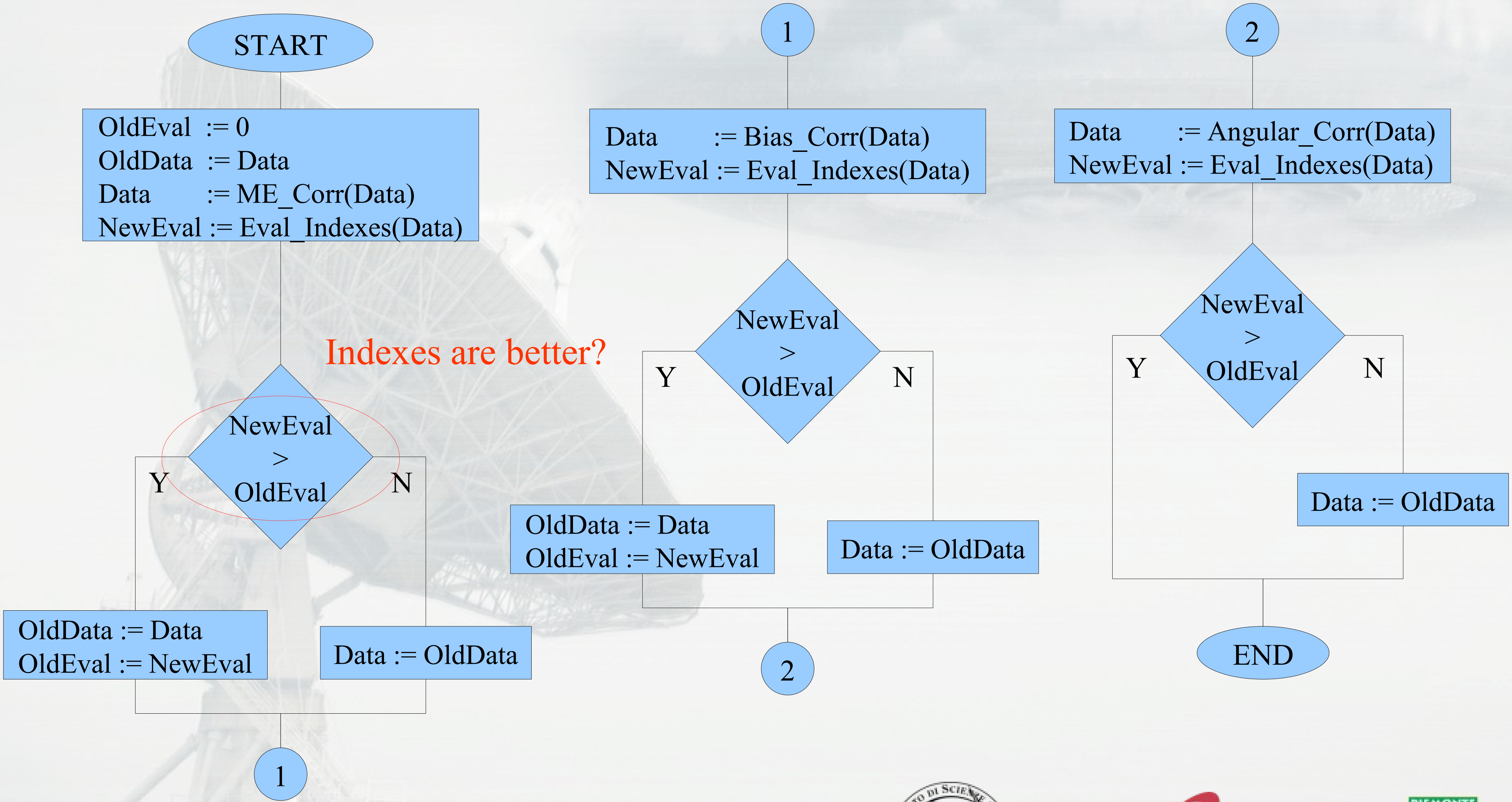
Algorithm explaination



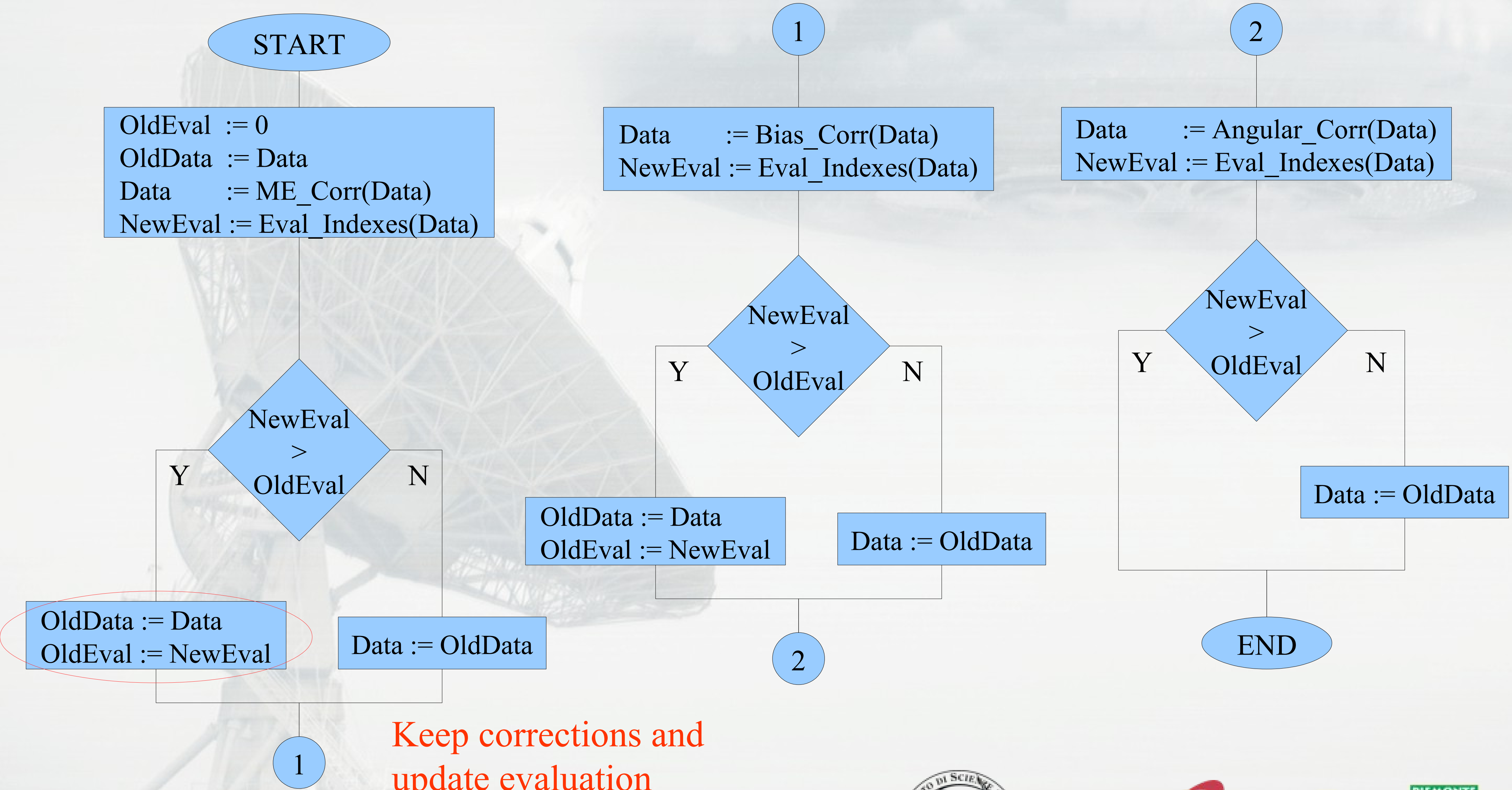
Algorithm explaination



Algorithm explaination

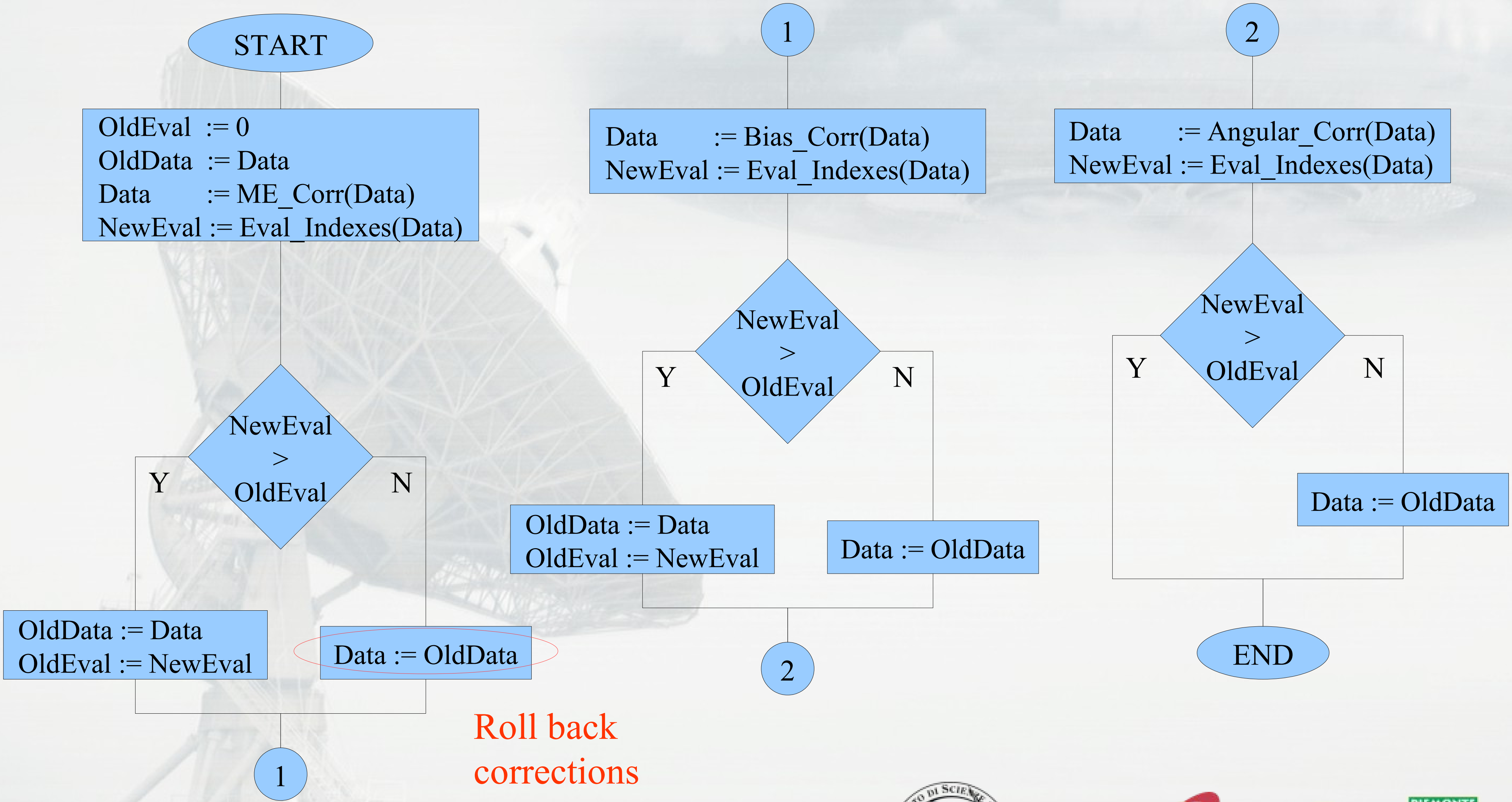


Algorithm explaination

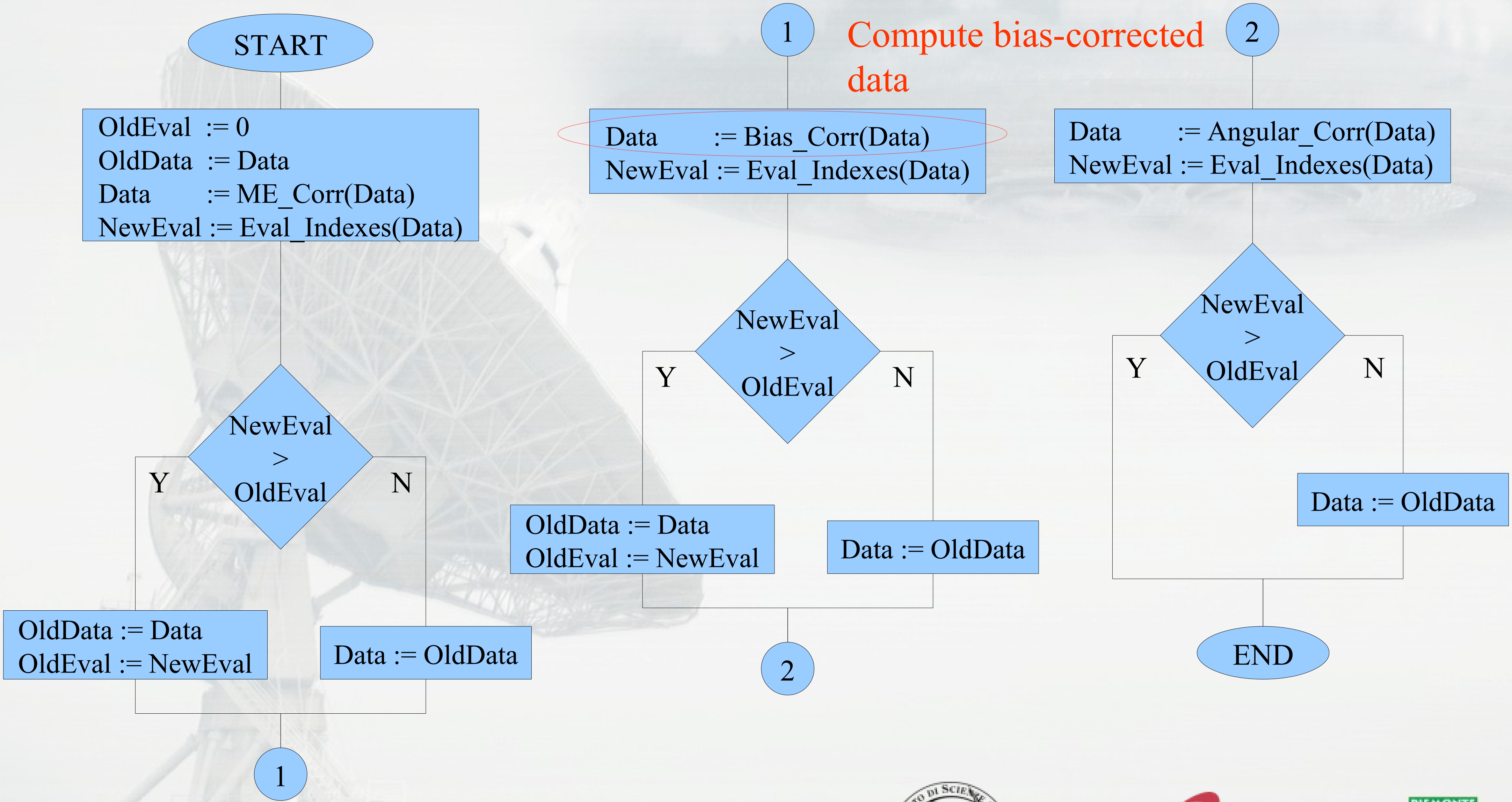


Keep corrections and update evaluation

Algorithm explaination



Algorithm explaination



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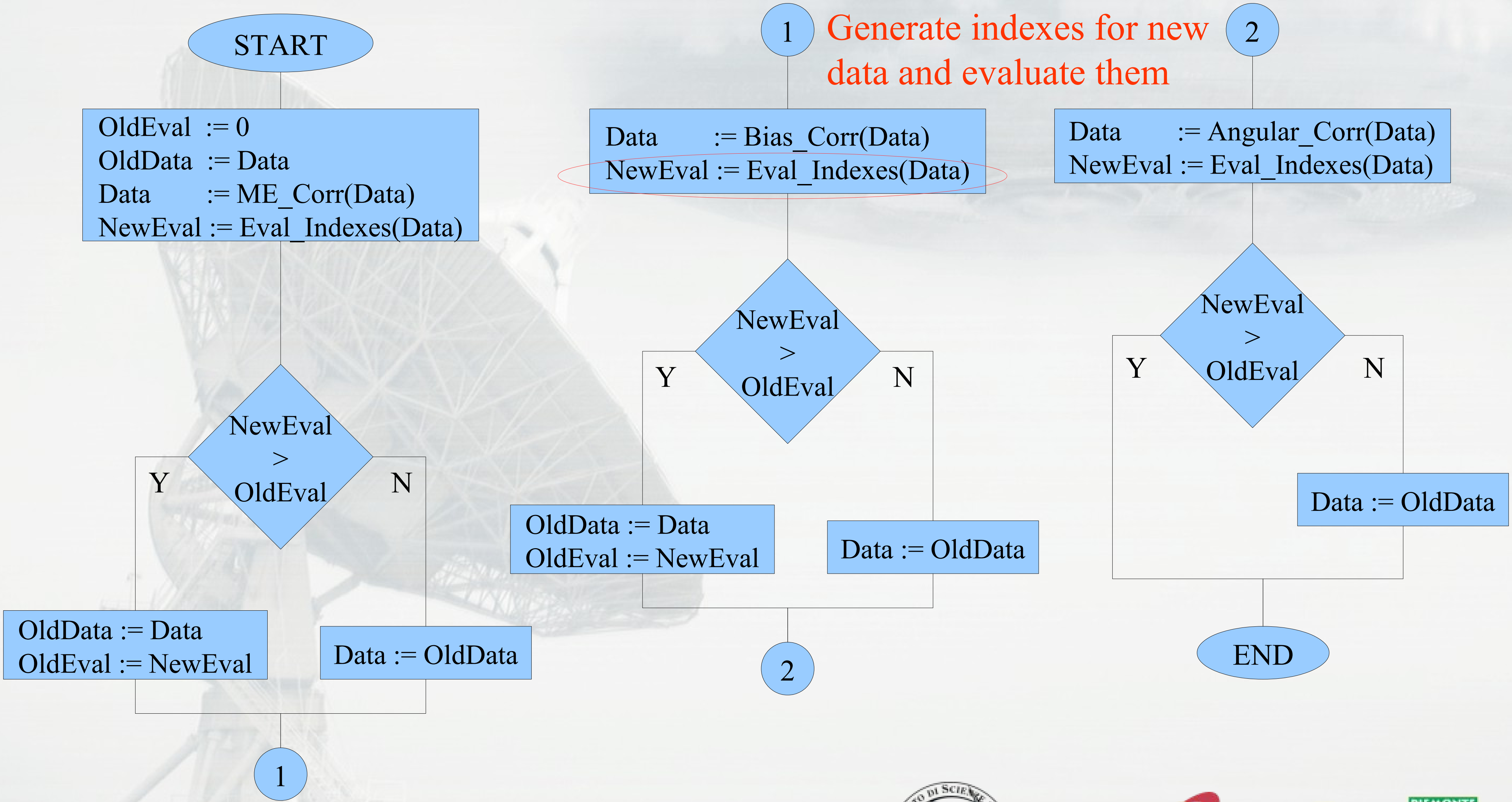

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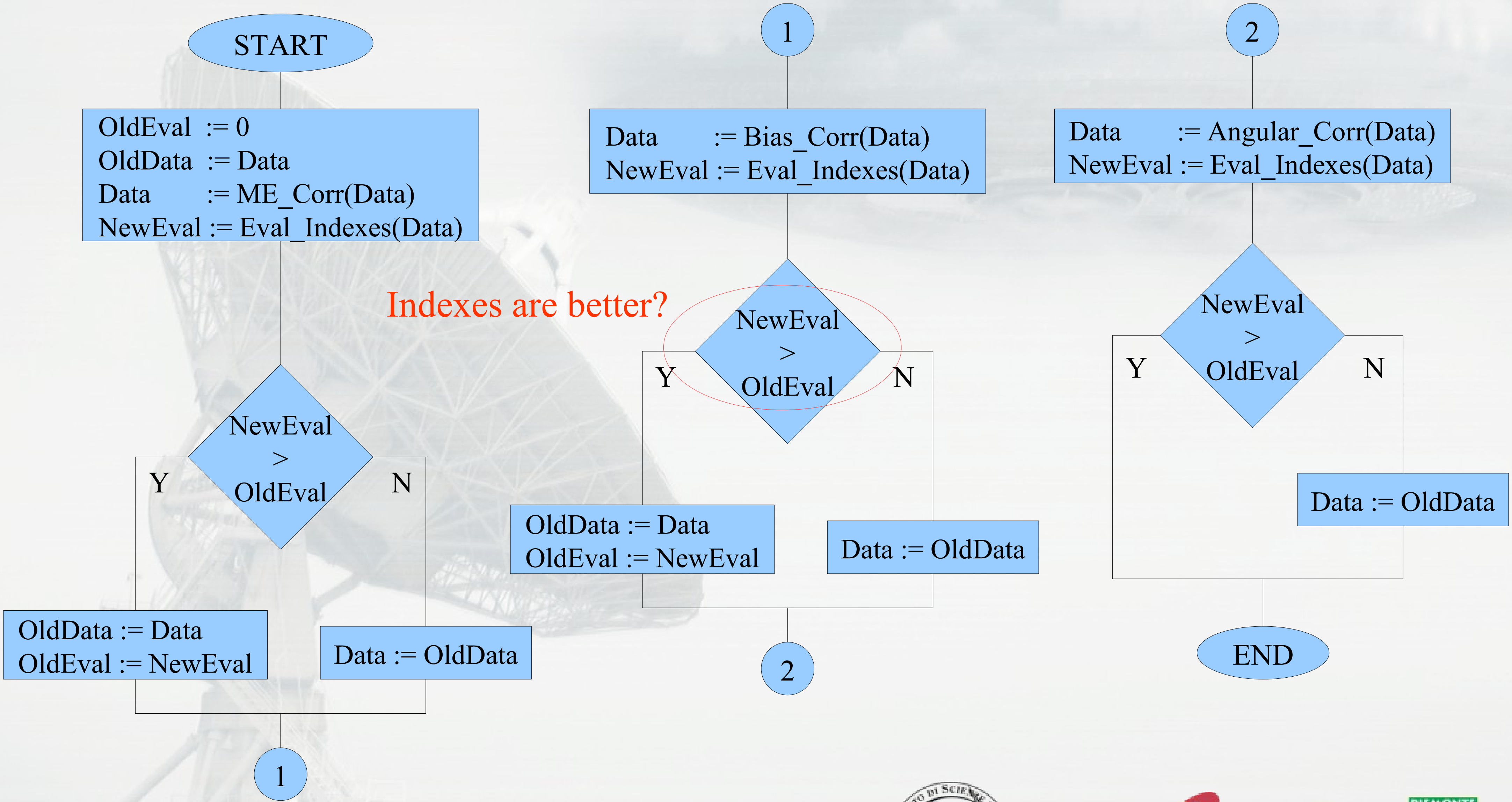

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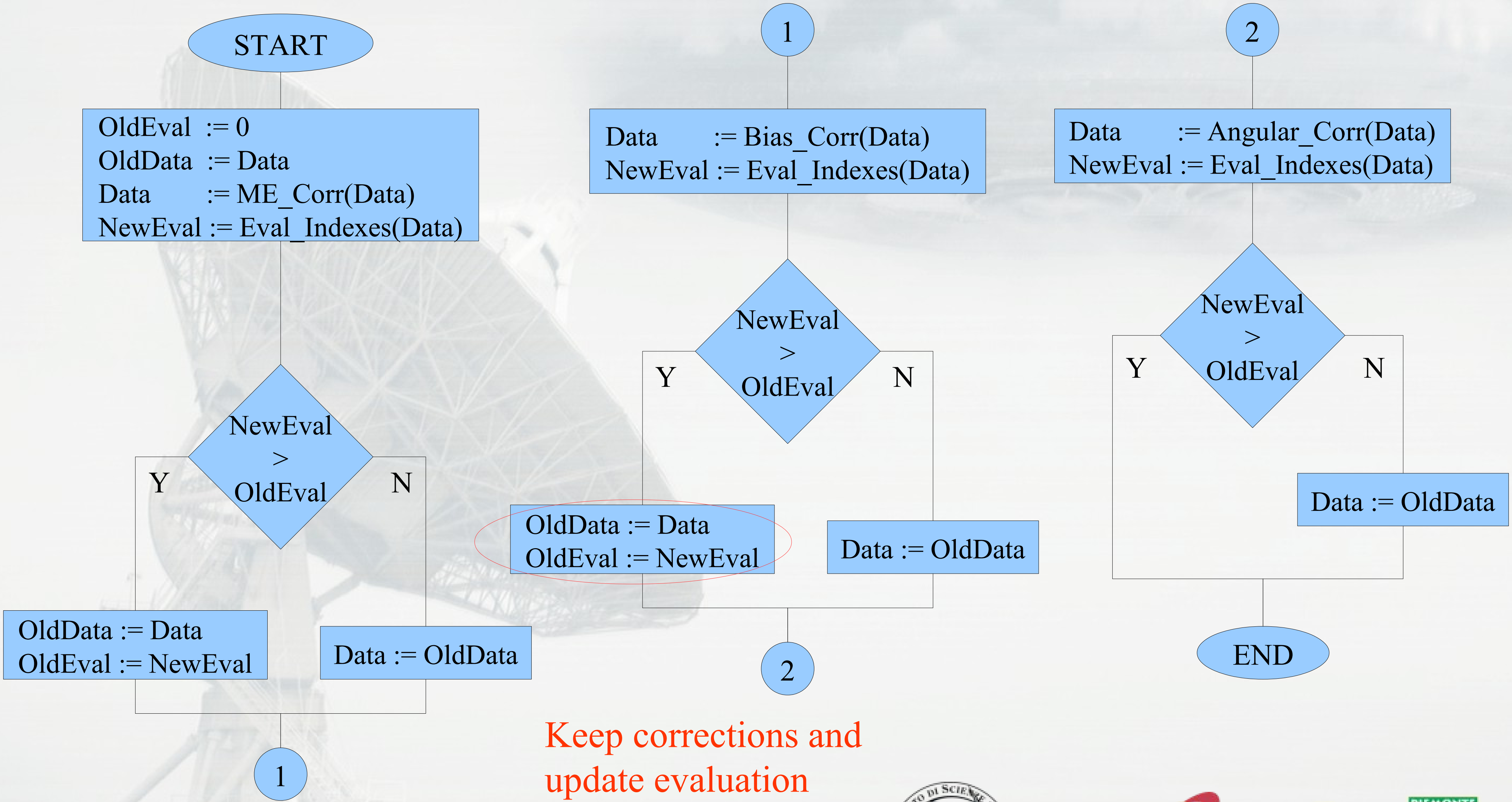
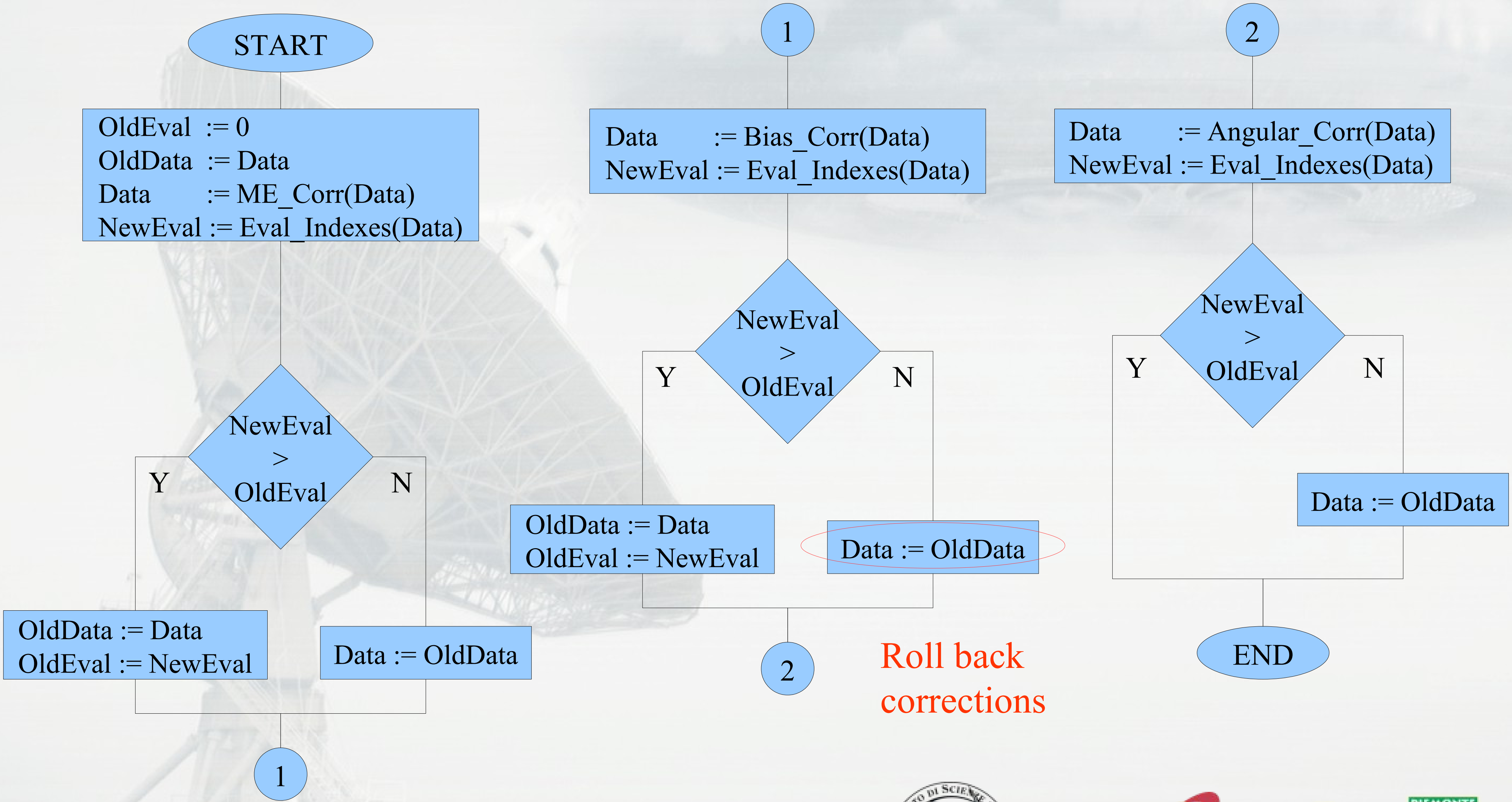
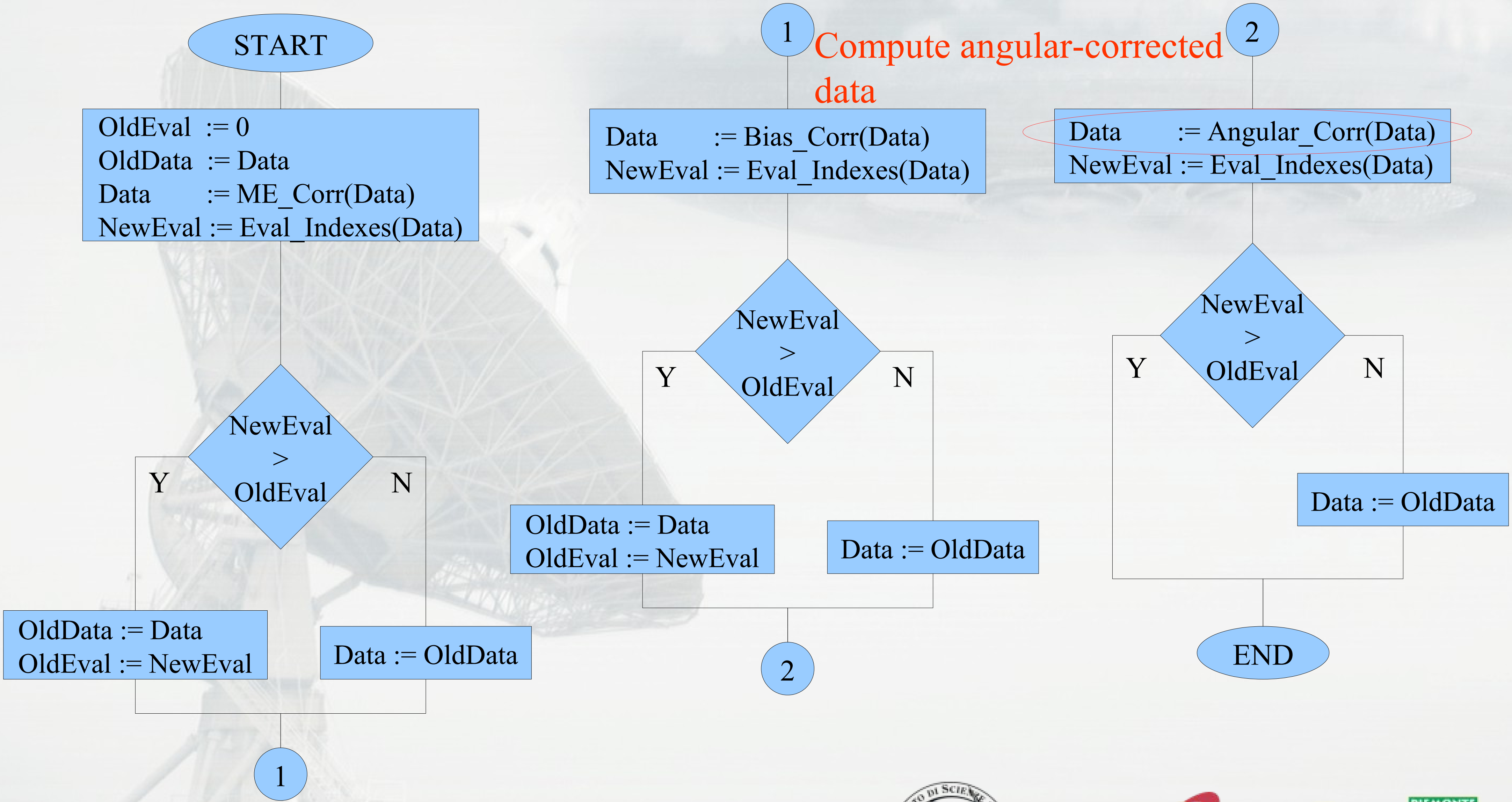


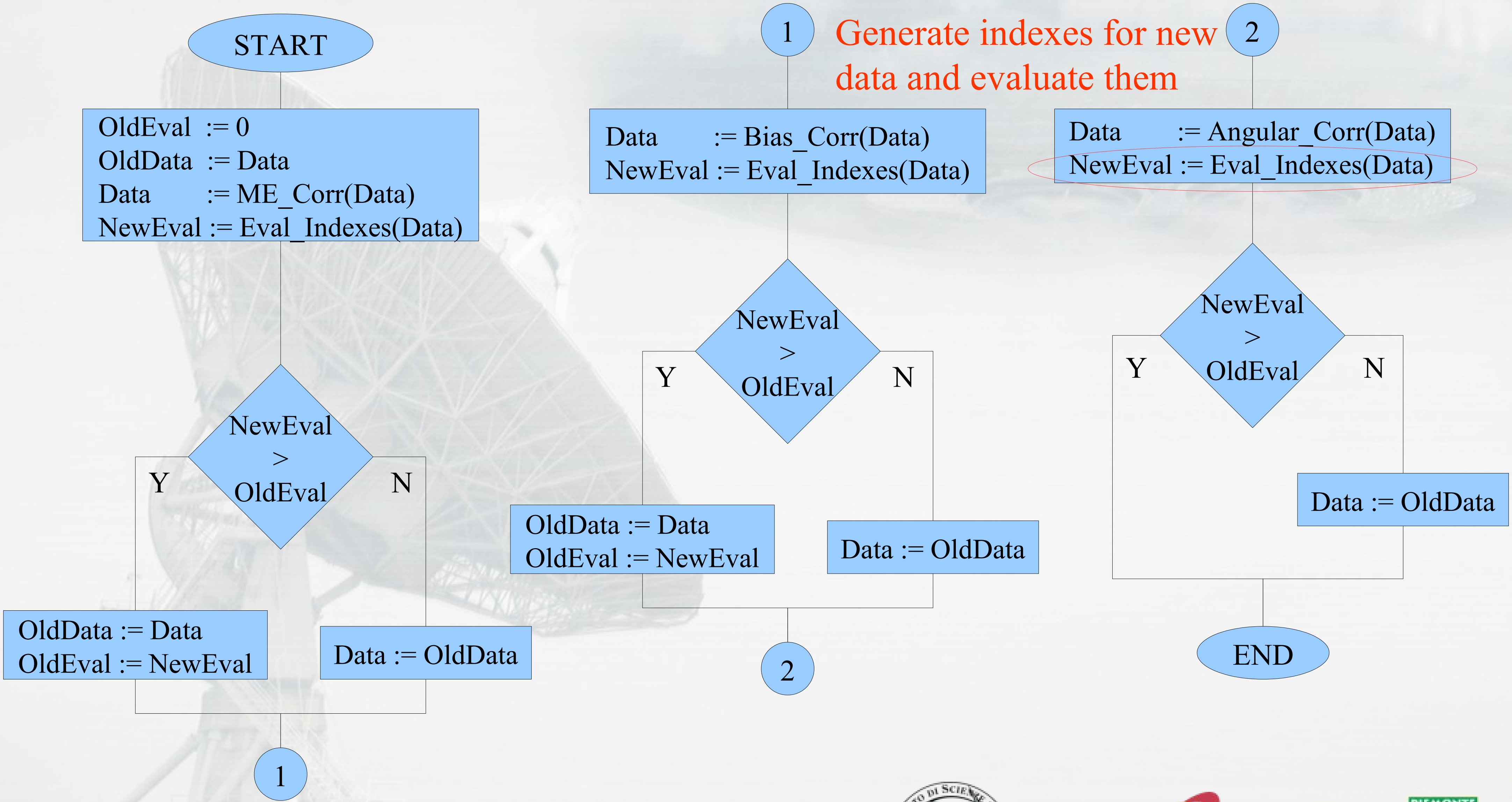
Algorithm explaination



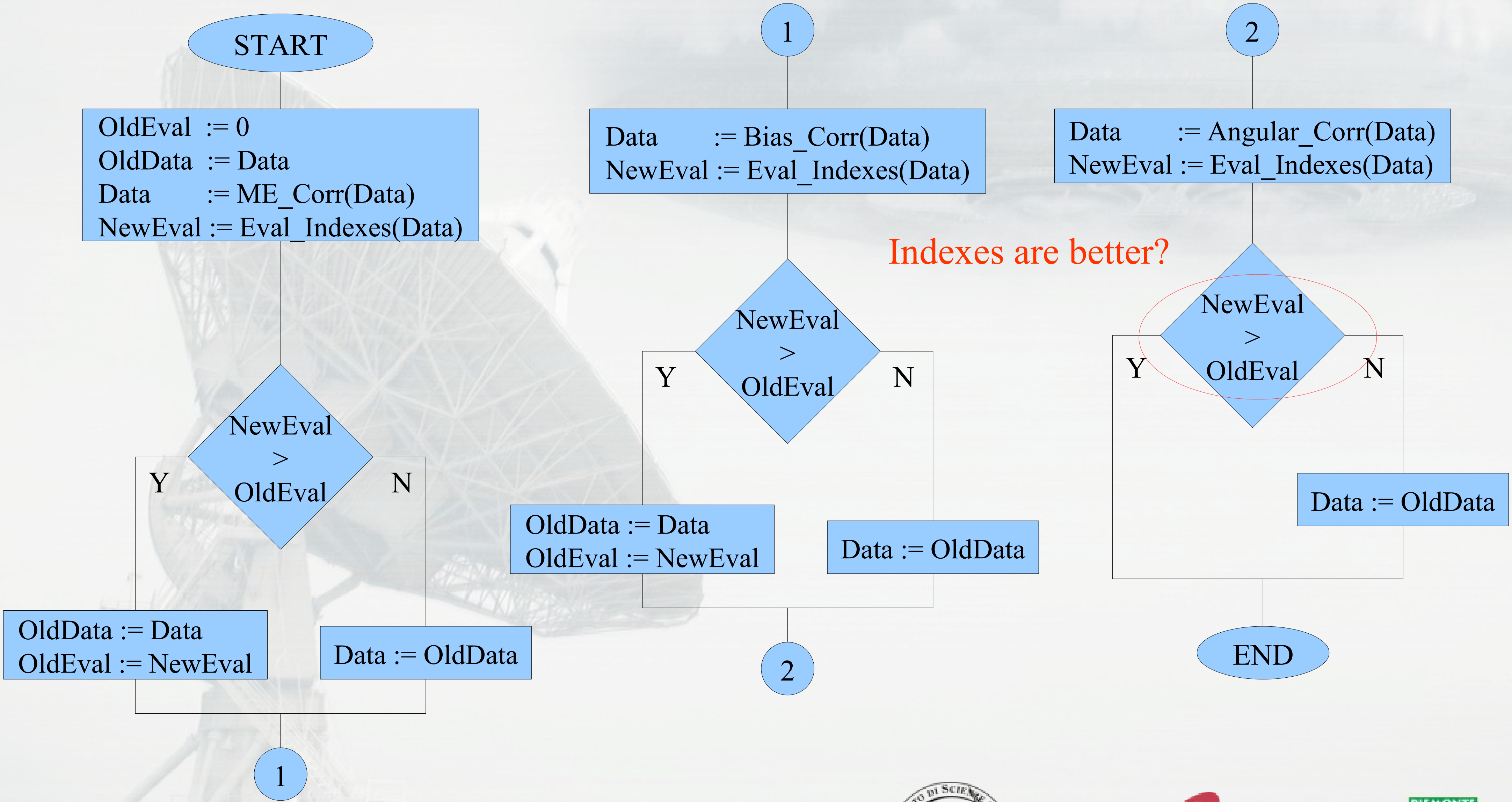
Algorithm explaination



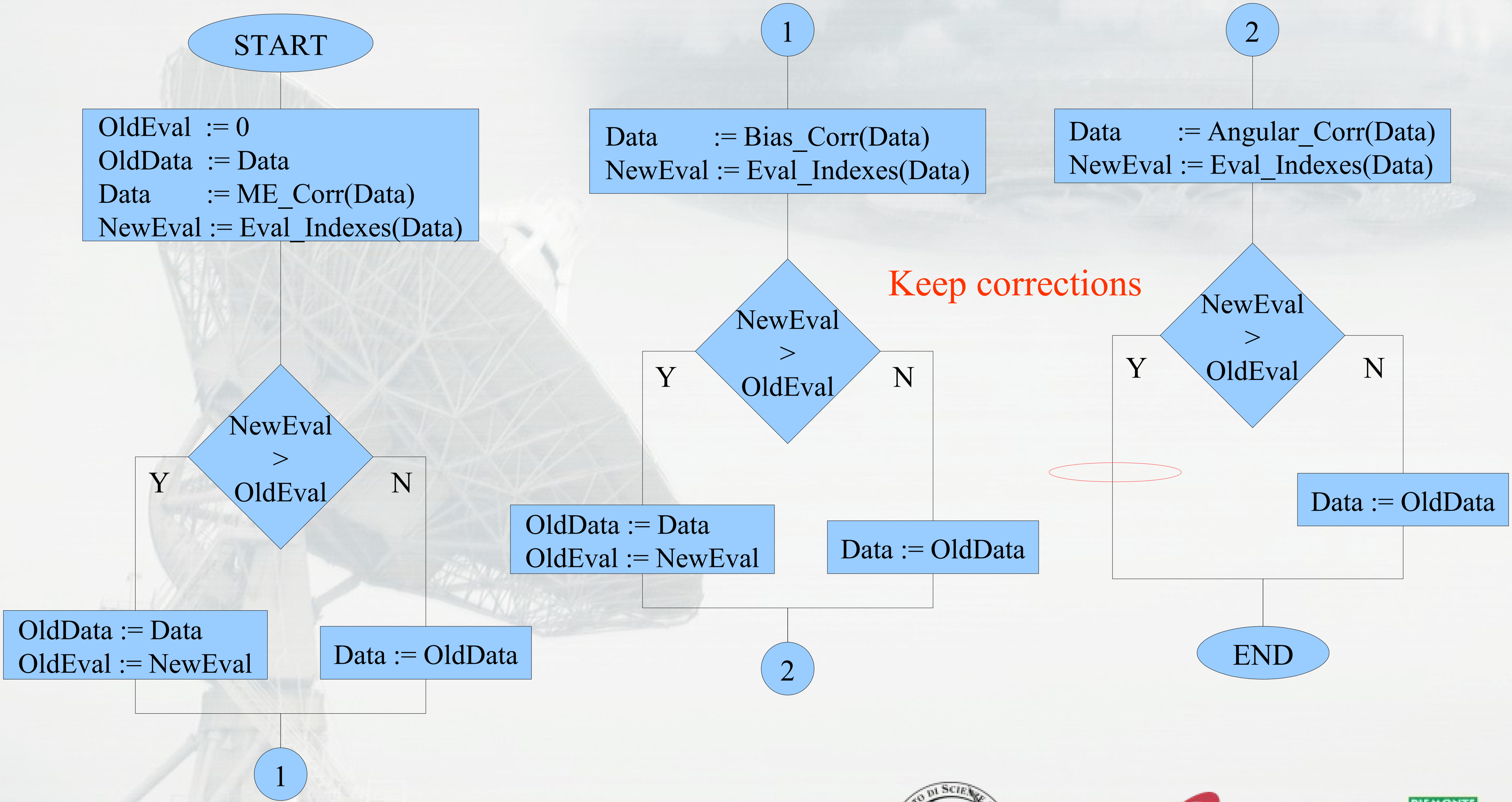
Algorithm explaination



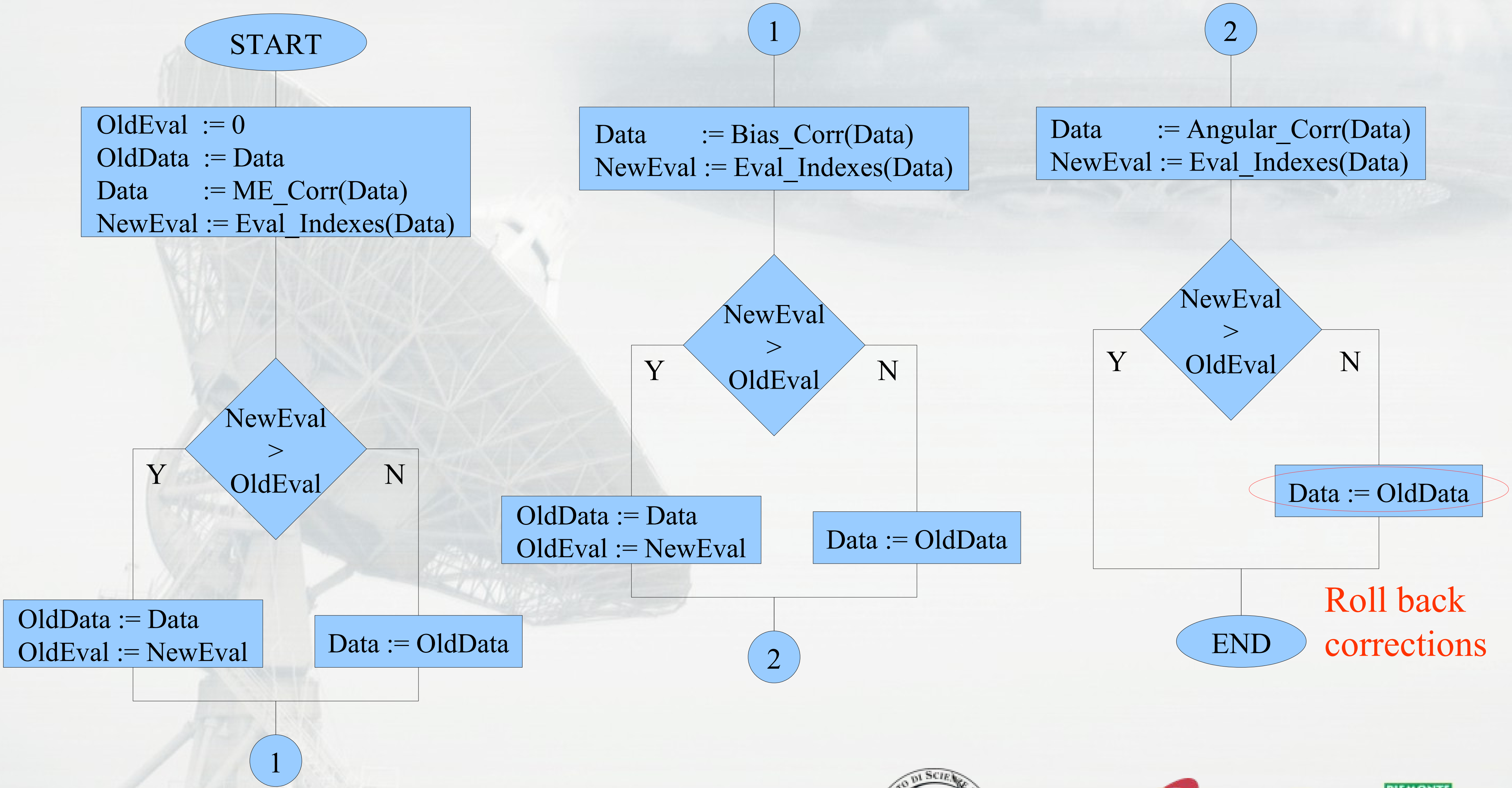
Algorithm explaination



Algorithm explaination

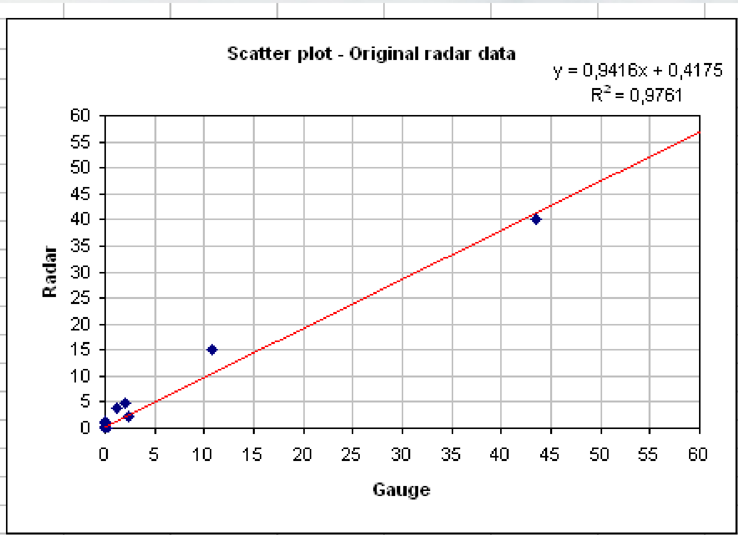


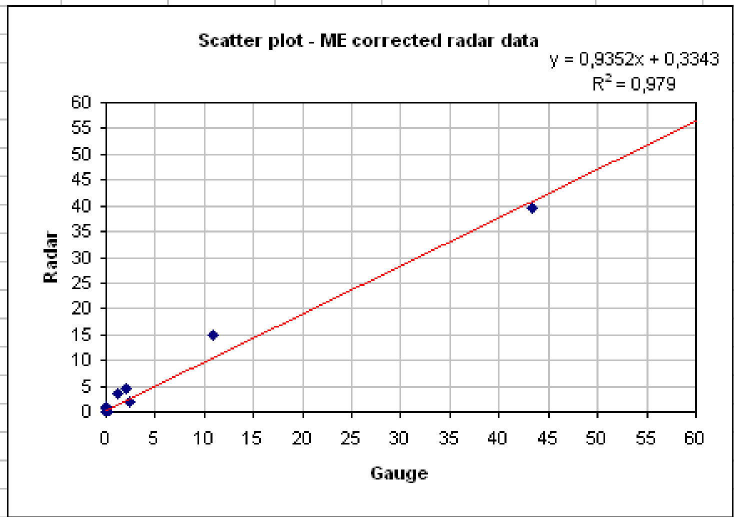
Algorithm explaination



Data optimization – Step 1

Coord		ID_staz	2014-07-28 h13-14		Original
X	Y		Gauge	Radar	Radar
413755	5019418	99	0,0	0,0	0,0
414152	4967469	102	0,0	0,0	0,0
373174	4980375	109	0,0	0,7	1,0
422382	5004180	110	0,0	0,0	0,0
381885	5016336	111	10,8	14,8	15,1
402828	4988482	120	0,0	0,0	0,0
407716	4975370	131	0,0	0,0	0,0
429242	4984323	139	0,0	0,0	0,0
373774	4994834	142	0,0	0,0	0,1
403991	4977715	180	0,0	0,0	0,0
396316	4971343	195	0,0	0,0	0,0
427500	4966004	204	0,0	0,0	0,0
421859	4996460	209	0,0	0,0	0,0
395441	5015494	247	0,0	0,0	0,0
395596	4985890	249	0,0	0,0	0,0
392460	4998970	256	0,0	0,0	0,0
398228	4979528	273	0,0	0,0	0,0
411791	4988907	274	0,0	0,0	0,0
375630	4988307	278	0,0	0,0	0,2
414707	4956203	332	0,0	0,0	0,0
371184	5006333	350	1,2	3,7	4,0
379872	5005760	351	2,4	2,0	2,3
381427	4963366	370	0,0	0,0	0,3
409882	5004010	373	0,2	0,0	0,0
381063	5014078	415	43,4	39,7	40,0
386008	5018529	428	2,0	4,6	4,9
397112	4991946	446	0,0	0,0	0,0
409921	5015808	S2573	0,0	0,7	1,0
394093	5004633	S2896	0,0	0,0	0,0
412336	5000464	S3098	0,0	0,0	0,0
396054	4992433	S3447	0,0	0,0	0,0
370552	4973026	S3685	0,0	0,7	1,0
395535	4996506	S3869	0,2	0,0	0,0
381938	4993117	S3948	0,0	1,1	1,4
416001	4985910	S4195	0,0	0,0	0,0





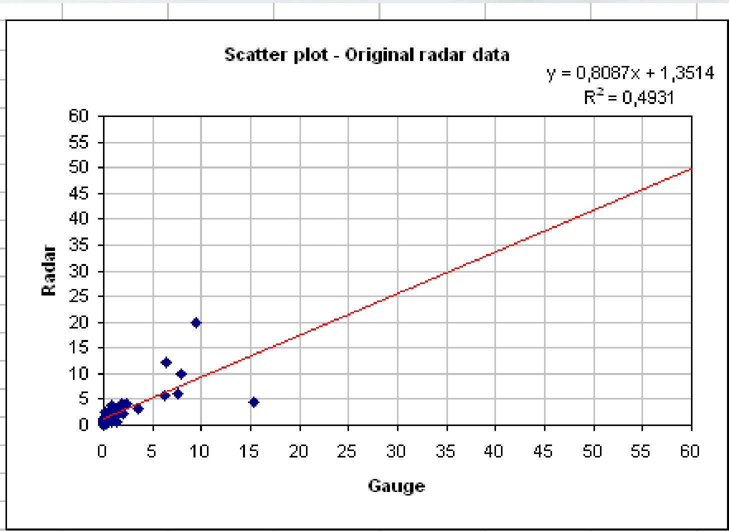
INDEXES			
Total precipitation in the area (TP)	60,2000	68,0000	71,2999
Mean precipitation in the area (MP)	1,7200	1,9429	2,0371
Max precipitation in the area (XP)	43,4000	39,7000	40,0000
Min precipitation in the area (NP)	0,0000	0,0000	0,0000
Mean error (ME)	0,0000	0,2184	0,3171
Mean absolute error (MAE)	0,0000	0,4776	0,5400
Relative MAE (RMAE)	0,0000	0,2776	0,3140
Root mean square error (RMSE)	0,0000	1,1382	1,2129
Mean bias with zeroes (MB)	1,0000	0,1085	0,1015
Mean bias without zeroes (MB-0)	1,0000	0,7594	0,7104

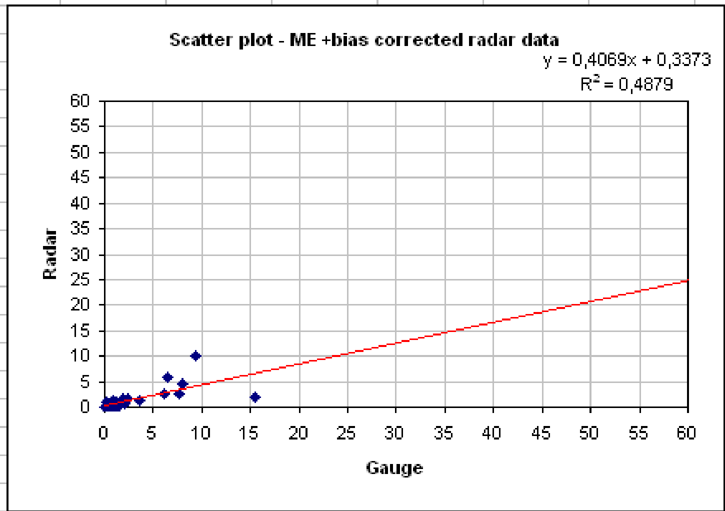
- Green = corrected radar data is better than original one
- Red = corrected radar data is worst than original one
- White = same value of the original one

- ME correction = radar data - ME, preventing negative values

Data optimization – Step 2

Coord		ID_staz	2014-07-29 h15-16		Original
X	Y		Gauge	Radar	Radar
413755	5019418	99	0,0	0,0	0,4
414152	4967469	102	15,4	1,9	4,5
373174	4980375	109	0,0	0,0	0,1
422382	5004180	110	0,2	0,9	2,7
381885	5016336	111	0,0	0,0	0,7
402828	4988482	120	1,8	1,1	3,1
407716	4975370	131	3,6	1,2	3,3
429242	4984323	139	6,2	2,6	5,9
373774	4994834	142	0,4	0,0	0,4
403991	4977715	180	2,0	0,7	2,2
396316	4971343	195	0,8	0,0	0,6
427500	4966004	204	9,4	9,9	19,9
421859	4996460	209	6,4	5,9	12,2
395441	5015494	247	0,0	0,0	0,9
395596	4985890	249	1,6	1,0	2,8
392460	4998970	256	1,2	1,1	3,1
398228	4979528	273	1,4	0,5	2,0
411791	4988907	274	7,6	2,7	6,2
375630	4988307	278	0,0	0,0	0,3
414707	4956203	332	1,4	0,0	0,5
371184	5006333	350	0,0	0,0	0,1
379872	5005760	351	0,2	0,0	0,8
381427	4963366	370	0,0	0,1	1,2
409882	5004010	373	0,6	0,9	2,6
381063	5014078	415	0,0	0,1	1,2
386008	5018529	428	0,0	0,0	0,4
397112	4991946	446	2,4	1,7	4,3
409921	5015808	S2573	0,0	0,0	0,5
394093	5004633	S2896	0,2	0,9	2,6
412336	5000464	S3098	0,8	1,1	3,1
396054	4992433	S3447	1,8	1,6	4,1
370552	4973026	S3685	0,0	0,0	0,1
395535	4996506	S3869	0,8	1,4	3,7
381938	4993117	S3948	0,0	0,0	0,8
416001	4985910	S4195	8,0	4,7	10,0





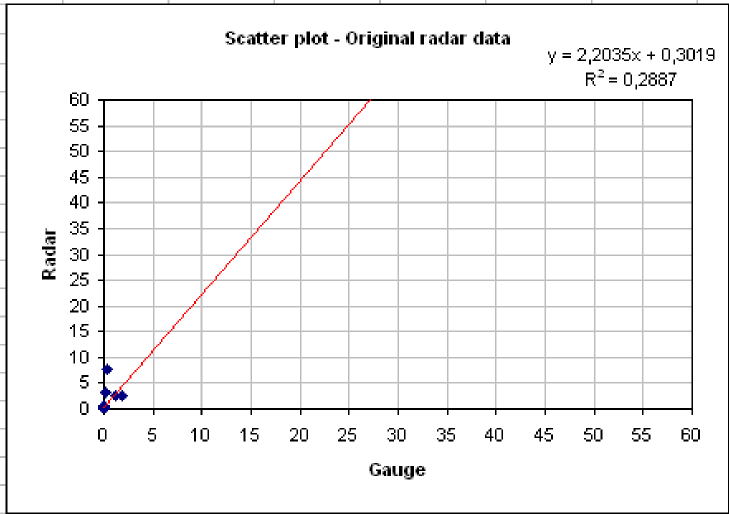
INDEXES			
Total precipitation in the area (TP)	74,2000	42,0000	107,3001
Mean precipitation in the area (MP)	2,1200	1,2000	3,0657
Max precipitation in the area (XP)	15,4000	9,9000	19,9000
Min precipitation in the area (NP)	0,0000	0,0000	0,1000
Mean error (ME)	0,0000	-0,9169	0,9457
Mean absolute error (MAE)	0,0000	1,1073	1,7457
Relative MAE (RMAE)	0,0000	0,5223	0,8235
Root mean square error (RMSE)	0,0000	2,6482	3,0299
Mean bias with zeroes (MB)	1,0000	1,0000	0,5420
Mean bias without zeroes (MB-0)	1,0000	0,8545	2,5956

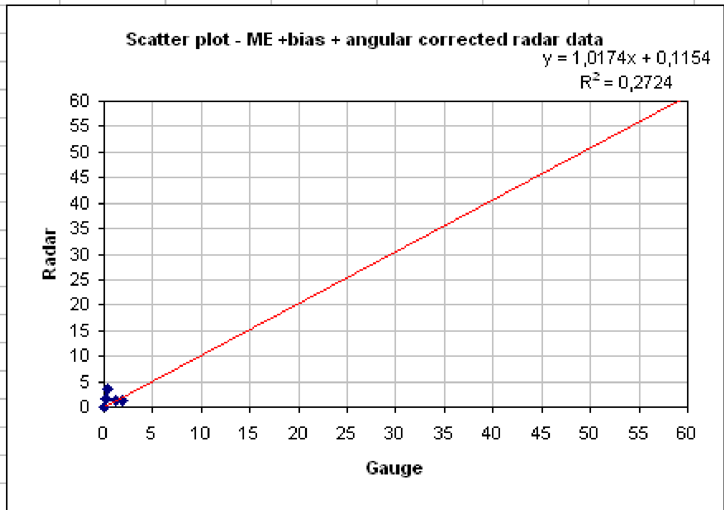
- Green = corrected radar data is better than original one
- Red = corrected radar data is worst than original one
- White = same value of the original one

- Bias correction = radar data * mean bias, if mean bias is within a threshold

Data optimization – Step 3

Coord X	Coord Y	ID_staz	2014-07-28 h12-13 Gauge	2014-07-28 h12-13 Radar	Original Radar
413755	5019418	99	0,0	0,0	0,0
414152	4967469	102	0,0	0,0	0,0
373174	4980375	109	0,0	0,0	0,0
422382	5004180	110	0,0	0,0	0,0
381885	5016336	111	0,0	0,1	0,6
402828	4988482	120	0,0	0,0	0,0
407716	4975370	131	0,0	0,0	0,0
429242	4984323	139	0,0	0,0	0,0
373774	4994834	142	0,0	0,0	0,4
403991	4977715	180	0,0	0,0	0,0
396316	4971343	195	0,0	0,0	0,0
427500	4966004	204	0,0	0,0	0,0
421859	4996460	209	0,0	0,0	0,0
395441	5015494	247	0,0	0,0	0,0
395596	4985890	249	0,0	0,0	0,0
392460	4998970	256	1,2	1,2	2,7
398228	4979528	273	0,0	0,0	0,0
411791	4988907	274	0,0	0,0	0,0
375630	4988307	278	0,0	0,0	0,1
414707	4956203	332	0,0	0,0	0,0
371184	5006333	350	0,0	0,0	0,4
379872	5005760	351	0,2	1,5	3,3
381427	4963366	370	0,0	0,0	0,0
409882	5004010	373	0,0	0,0	0,4
381063	5014078	415	0,4	3,7	7,7
386008	5018529	428	0,0	0,0	0,1
397112	4991946	446	0,0	0,0	0,0
409921	5015808	S2573	0,0	0,0	0,0
394093	5004633	S2896	0,0	0,0	0,0
412336	5000464	S3098	0,0	0,0	0,0
396054	4992433	S3447	0,0	0,0	0,0
370552	4973026	S3685	0,0	0,0	0,0
395535	4996506	S3869	1,8	1,2	2,7
381938	4993117	S3948	0,0	0,0	0,1
416001	4985910	S4195	0,0	0,0	0,0



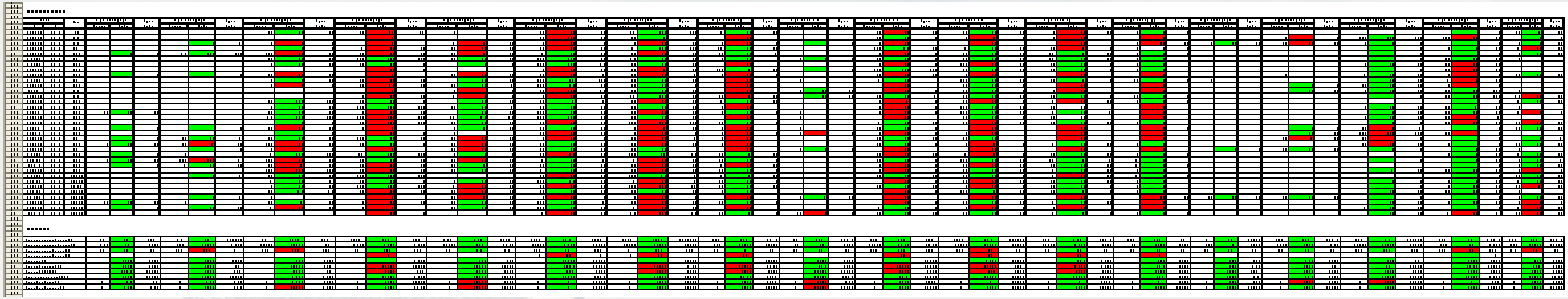


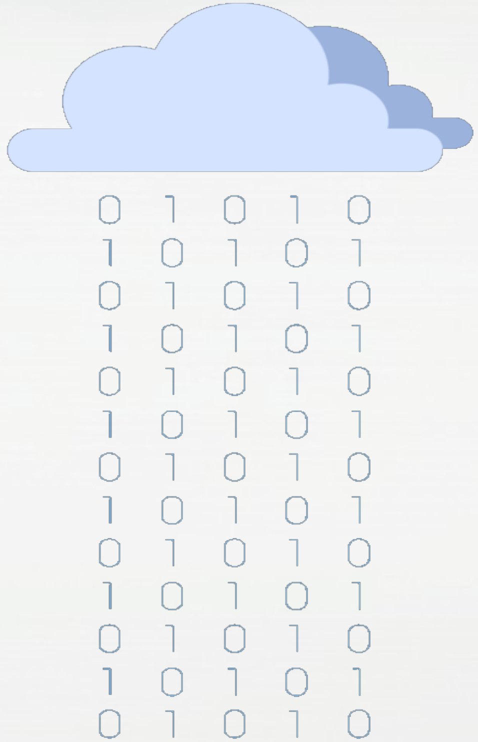
INDEXES			
Total precipitation in the area (TP)	3,6000	7,7000	18,5000
Mean precipitation in the area (MP)	0,1029	0,2200	0,5286
Max precipitation in the area (XP)	1,8000	3,7000	7,7000
Min precipitation in the area (NP)	0,0000	0,0000	0,0000
Mean error (ME)	0,0000	0,1154	0,4257
Mean absolute error (MAE)	0,0000	0,1533	0,4257
Relative MAE (RMAE)	0,0000	1,4906	4,1389
Root mean square error (RMSE)	0,0000	0,6134	1,3818
Mean bias with zeroes (MB)	1,0000	0,0803	0,0350
Mean bias without zeroes (MB-0)	1,0000	0,7026	0,3059

- Green = corrected radar data is better than original one
- Red = corrected radar data is worst than original one
- White = same value of the original one

- Angular correction = radar data * (1/angular coefficient)

Data optimization on different datasets

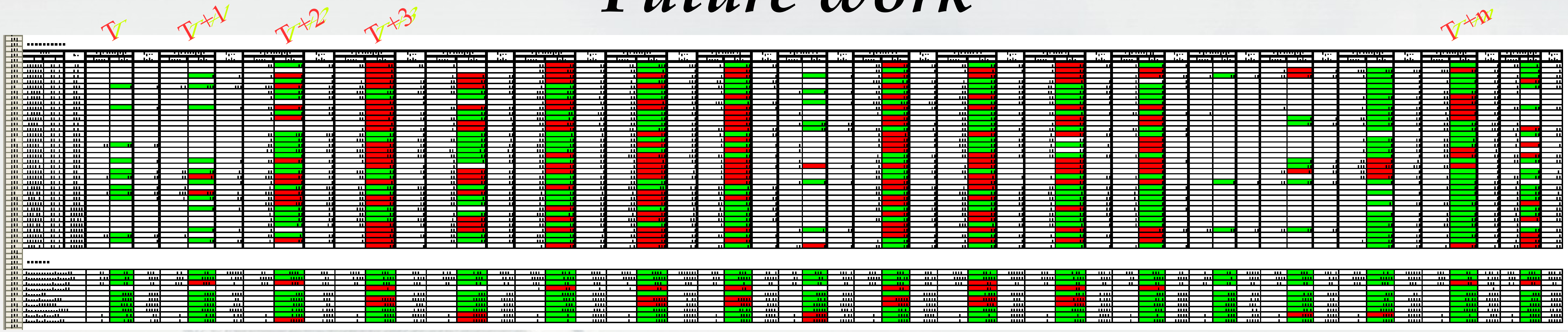




- 18 continuous datasets in two stormy July day (2014-07-28 and 29)
- Atomicity on the whole dataset, not on single weather station data
- Very good results obtained

- Upper part = hourly data per single station
- Lower part = indexes evaluation

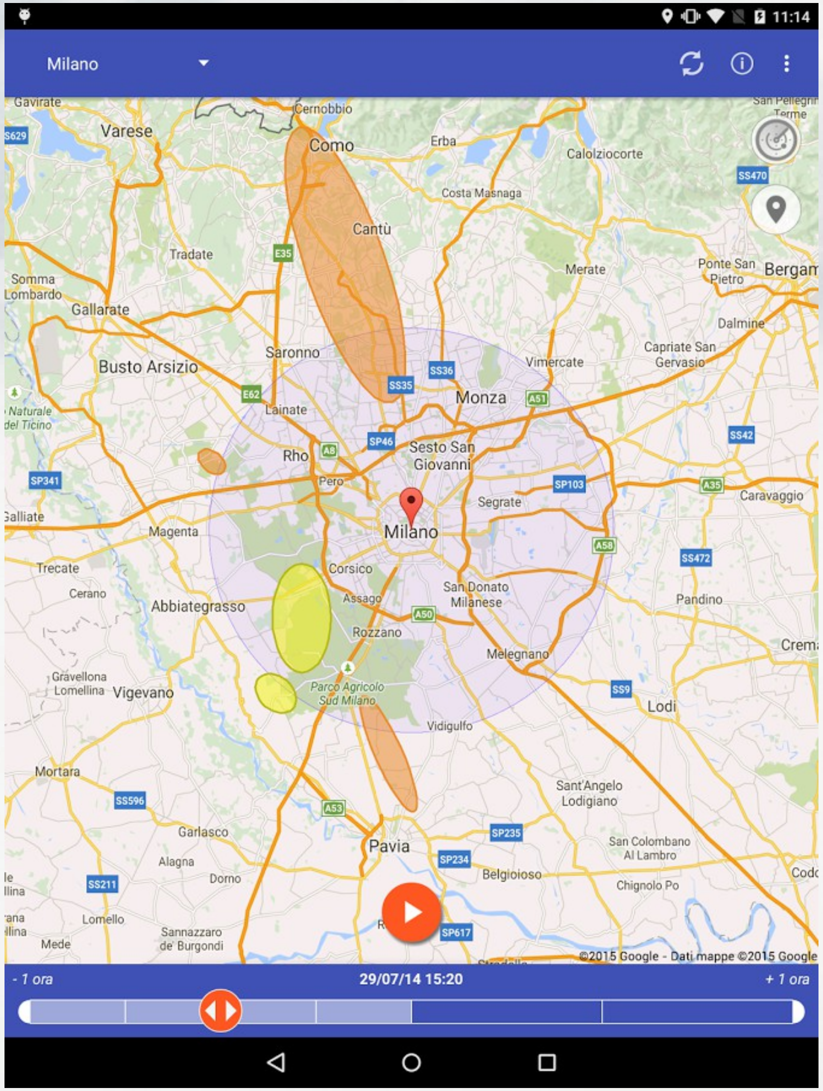
Future work



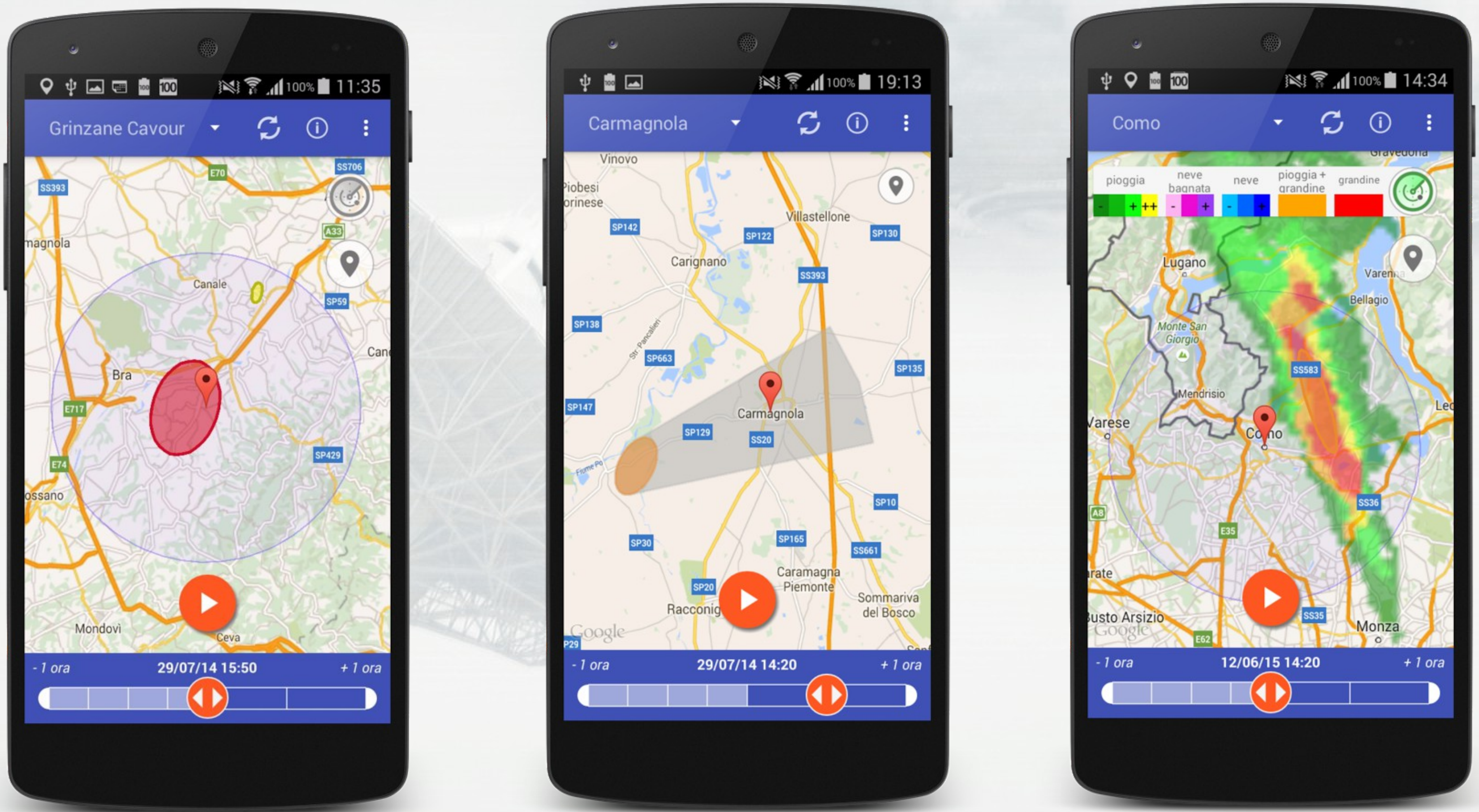
- This algorithm computes a better estimation of rainfall rates at time T only when we are at T+1
  - Works on past data
  - Sees all datasets like a single entity, not correlated with others
- Implement an algorithm that at time T+1 tries to estimate what is a good optimization for time T+1, using information obtained from time T
  - So... prediction!
- Is the method described here usable for nowcasting?
  - Maybe, but with some major modification
    - We necessary have to take into account a lot of other parameters (e.g.: wind speed and direction)
    - We should move from hourly data to 10-minute time slots to reduce differences between rain gauges and radar data
  - Works very well with advective precipitation but quality degrades with convective ones (which are the most dangerous for urban flooding events)

TemporAlert

- Android app for nowcasting
  - Available for free on Google Play
  - Covers the north west part of Italy
  - Based on weather radar data and GPS
  - High resolution (500 m updated every 5 min)
  - Identifies storm cells
  - Analyzes data from previous hour to next one
  - Notifies about incoming storms and severity
- To learn more:
  - http://www.csp.it/temporalert-una-app-di-arpa-e-csp-sugli-eventi-estremi/
  - http://ricerca.repubblica.it/repubblica/archivio/repubblica/2015/07/12/lallerta-temporale-scatta-sullo-smartphone-in-tempo-per-ripararsiTorino07.html
  - https://play.google.com/store/apps/details?id=it.csp.temporalert&hl=it

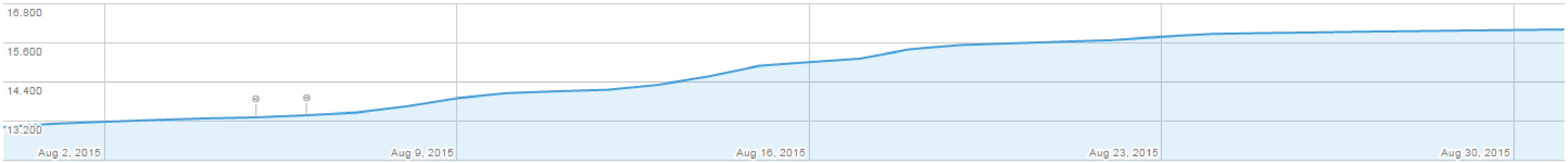


TemporAlert

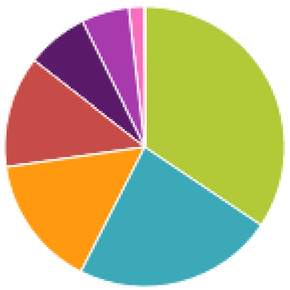


TemporAlert stats

The total number of unique users who have ever installed this app on one or more of their devices. Learn more



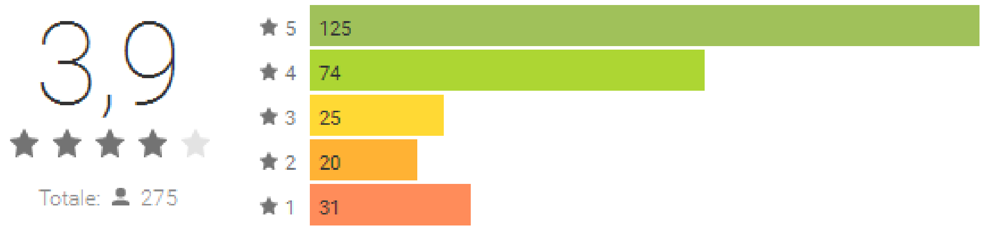
TOTAL INSTALLS BY USER ON AUG 31, 2015



	YOUR APP	
Android 4.4	5,513	34.43%
Android 5.0	3,697	23.09%
Android 4.2	2,431	15.18%
Android 4.1	2,057	12.85%
Android 4.3	1,138	7.11%
Android 5.1	882	5.51%
Android 4.0.3 - 4.0.4	287	1.79%
Others	8	0.05%

RECENSIONI

Scrivi una recensione



Roberto L ★★★★★
App meteo definitiva Dopo aver usato questa ogni altra diventa inutile..

Dario G ★★★★★
Ok Questa notte l'app ha funzionato avvisandomi del temporale. L'unica cosa è che

APP NAME	PRICE	CURRENT / TOTAL INSTALLS	AVG. RATING / TOTAL #	CRASHES & ANRS	LAST UPDATE	STATUS
TemporALERT! 1.1.1b	Free	13,012 / 16,013	★ 3.89 / 271	18	Aug 6, 2015	Published

Questions and suggestions?

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