SWNM

March 25, 2021

0.1 Geothermal machine learning analysis: Southwest New Mexico

This notebook is a part of the GTcloud.jl: GeoThermal Cloud for Machine Learning.

```
<img src="../../logos/geothermalcloud-small.png" alt="geothermalcloud" width=25%  max-width=125
```

Machine learning analyses are performed using the **SmartTensors** machine learning framework.

```
<img src="../../logos/SmartTensorsNewSmaller.png" alt="SmartTensors" width=25%  max-width=125px
```

This notebook demonstrates how the **NMFk** module of **SmartTensors** can be applied to perform unsupervised geothermal machine-learning analyses.

```
<img src="../../logos/nmfk-logo.png" alt="nmfk" width=25%  max-width=125px;/>
```

More information how the ML results are interpreted to provide geothermal insights is discussed in our research paper.

0.2 Import required libraries for this work

If **NMFk** is not installed, first execute in the Julia REPL `import Pkg; Pkg.add("NMFk"); Pkg.add("DelimitedFiles"); Pkg.add("JLD"); Pkg.add("Gadfly"); Pkg.add("Cairo"); Pkg.add("Fontconfig"); Pkg.add("Mads")`.

[1]:
```
import NMFk
import DelimitedFiles
import JLD
import Gadfly
import Cairo
import Fontconfig
import Mads
```

0.3 Load and pre-process the data

0.3.1 Setup the working directory containing the SWNM data

[2]:
```
cd("/Users/vvv/Julia/GTcloud-SmartTensors.jl/SWNM");
```

0.3.2 Load the data file

[3]:
```
d, h = DelimitedFiles.readdlm("data/Pepin_PCA_Input_Data_LANL.csv", ',';␣
↪header=true);
```

0.3.3 Define names of the data attributes (matrix columns)

[4]:
```
attributes_short = ["Boron"; "Gravity"; "Magnetic"; "Dikes"; "Drainage";␣
↪"FaultInter"; "QuatFaults"; "Seismicity"; "NMFaults"; "Springs"; "Vents";␣
↪"Lithium"; "Precip"; "Air_Temp"; "Silica"; "Subcrop"; "WT_Gradient";␣
↪"WT_Elev"; "Heatflow"; "GS_Elev"; "DTW"; "Crst_Thick"; "Bsmt_Depth"]
attributes_long = uppercasefirst.(lowercase.(["Boron Concentration"; "Gravity␣
↪Anomaly"; "Magnetic Intensity"; "Volcanic Dike Density"; "Drainage Density";␣
↪"Fault Intersection Density"; "Quaternary Fault Density"; "Seismicity";␣
↪"State Map Fault Density"; "Spring Density"; "Volcanic Vent Density";␣
↪"Lithium Concentration"; "Precipitation"; "Air Temperature"; "Silica␣
↪Geothermometer"; "Subcrop Permeability"; "Hydraulic Gradient"; "Watertable␣
↪Elevation"; "Heat flow"; "Groundsurface Elevation"; "Watertable Depth";␣
↪"Crustal Thickness"; "Depth to Basement"]))
attributes_long_new = uppercasefirst.(lowercase.(["Boron"; "Gravity anomaly";␣
↪"Magnetic intensity"; "Volcanic dike density"; "Drainage density"; "Fault␣
↪intersection density"; "Quaternary fault density"; "Seismicity"; "State map␣
↪fault density"; "Spring density"; "Volcanic vent density"; "Lithium";␣
↪"Precipitation"; "Air temperature"; "Silica geothermometer"; "Subcrop␣
↪permeability"; "Hydraulic gradient"; "Watertable elevation"; "Heat flow";␣
↪"Groundsurface elevation"; "Watertable depth"; "Crustal thickness"; "Depth␣
↪to basement"]))
attributes_ordered = ["Boron concentration", "Lithium concentration", "Drainage␣
↪density", "Spring density", "Hydraulic gradient", "Precipitation", "Gravity␣
↪anomaly", "Magnetic intensity", "Seismicity", "Silica geothermometer", "Heat␣
↪flow", "Crustal thickness", "Depth to basement", "Fault intersection␣
↪density", "Quaternary fault density", "State map fault density", "Volcanic␣
↪dike density", "Volcanic vent density"];
```

Short attribute names are used for coding.

Long attribute names are used for plotting and visualization.

0.3.4 Define attributes to remove from analysis

[5]:
```
attributes_remove = uppercasefirst.(lowercase.(["Air Temperature"; "Subcrop␣
↪Permeability"; "Watertable Elevation"; "Groundsurface Elevation";␣
↪"Watertable Depth"]));
```

0.3.5 Define attributes for analysis

[6]:
```
index_remove = indexin(attributes_remove, attributes_long)
attributes_cols = trues(length(attributes_long))
attributes_cols[index_remove] .= false
cols = vec(4:26)[attributes_cols]
attributes = attributes_long[cols .- 3];
```

0.3.6 Define names of the data locations

[7]:
```
locations_short = ["Alamos spr";
"Allen spr";
"Apache well";
"Aragon spr";
"Ash spr";
"B.Iorio well";
"Cliff spr";
"Dent well";
"Derry spr";
"Faywood spr";
"Fed H1 well";
"Freiborn spr";
"Garton well";
"Gila spr 1";
"Gila spr 2";
"Goat spr";
"Jerry well";
"Kennecott well";
"Laguna Pbl";
"Lightning Dock";
"Los Alturas";
"Mangas spr";
"Mimbres spr";
"Ojitos spr";
"Ojo Caliente";
"Ojo Canas";
"Pueblo well";
"Radium spr";
"Rainbow spr";
"Riverside well";
"Sacred spr";
"Socorro Can";
"Spring";
"Spring Can";
"T or C spr";
"Turkey spr";
"Victoria well";
"Warm spr";
```

```
"Well 1";
"Well 2";
"Well 3";
"Well 4";
"Well 5";
"Carne well"]

locations_long = ["Alamos Spring";
"Allen Springs";
"Apache Tejo Warm Springs well";
"Aragon Springs";
"Ash Spring";
"B. Iorio 1 well";
"Cliff Warm Spring";
"Dent windmill well";
"Derry Warm Springs";
"Faywood Hot Springs";
"Federal H 1 well";
"Freiborn Canyon Spring";
"Garton well";
"Gila Hot Springs 1";
"Gila Hot Springs 2";
"Goat Camp Spring";
"Jerry well";
"Kennecott Warm Springs well";
"Laguna Pueblo";
"Lightning Dock";
"Los Alturas Estates";
"Mangas Springs";
"Mimbres Hot Springs";
"Ojitos Springs";
"Ojo Caliente";
"Ojo De las Canas";
"Pueblo windmill well";
"Radium Hot Springs";
"Rainbow Spring";
"Riverside Store well";
"Sacred Spring";
"Socorro Canyon";
"Spring";
"Spring Canyon Warm Spring";
"Truth or Consequences spring";
"Turkey Creek Spring";
"Victoria Land and Cattle Co. well";
"Warm Springs";
"Well 1";
"Well 2";
```

```
"Well 3";
"Well 4";
"Well 5";
"Well south of Carne"];
```

Short location names are used for coding.

Long location names are used for plotting and visualization.

0.3.7 Define location coordinates

[8]:
```
dindex = d[:,end] .== 1
rows = convert.(Int32, d[dindex,end-1])
locations = locations_short[rows]
lat = d[dindex, 2]
lon = d[dindex, 3];
```

0.3.8 Set up directories tp store results and figures

[9]:
```
figuredir = "figures-case01"
resultdir = "results-case01";
```

0.3.9 Define a range for number of signatures to be explored

[10]:
```
nkrange = 2:10;
```

0.3.10 Define and normalize the data matrix

[11]:
```
X = permutedims(d[dindex, cols])
Xu, nmin, nmax = NMFk.normalizematrix_row!(X);
```

0.4 Perform ML analyses

The **NMFk** algorithm factorizes the normalized data matrix `Xu` into `W` and `H` matrices. For more information, check out the **NMFk** website

[12]:
```
W, H, fitquality, robustness, aic = NMFk.execute(Xu, nkrange, 1000;␣
 ↪resultdir=resultdir, casefilename="nmfk", load=true)
W, H, fitquality, robustness, aic = NMFk.load(nkrange, 1000;␣
 ↪resultdir=resultdir, casefilename="nmfk");
```

```
Signals:  2 Fit:     32.70151 Silhouette:            1 AIC:    -2276.215
Signals:  3 Fit:      24.6022 Silhouette:    0.9999996 AIC:    -2377.607
Signals:  4 Fit:     18.46274 Silhouette:    0.9999994 AIC:    -2480.975
Signals:  5 Fit:     14.74592 Silhouette:     0.764538 AIC:    -2535.007
Signals:  6 Fit:      12.3538 Silhouette:   -0.1423047 AIC:    -2551.193
Signals:  7 Fit:     10.29325 Silhouette:   -0.0733191 AIC:    -2571.714
Signals:  8 Fit:     8.237522 Silhouette:    0.2518114 AIC:    -2624.163
Signals:  9 Fit:     7.607165 Silhouette:  -0.07981342 AIC:    -2563.213
```

```
Signals: 10 Fit:     6.023938 Silhouette:   0.02130362 AIC:    -2624.026
Signals:  2 Fit:     32.70151 Silhouette:            1 AIC:    -2276.215
Signals:  3 Fit:      24.6022 Silhouette:    0.9999996 AIC:    -2377.607
Signals:  4 Fit:     18.46274 Silhouette:    0.9999994 AIC:    -2480.975
Signals:  5 Fit:     14.74592 Silhouette:     0.764538 AIC:    -2535.007
Signals:  6 Fit:      12.3538 Silhouette:   -0.1423047 AIC:    -2551.193
Signals:  7 Fit:     10.29325 Silhouette:   -0.0733191 AIC:    -2571.714
Signals:  8 Fit:     8.237522 Silhouette:    0.2518114 AIC:    -2624.163
Signals:  9 Fit:     7.607165 Silhouette:  -0.07981342 AIC:    -2563.213
Signals: 10 Fit:     6.023938 Silhouette:   0.02130362 AIC:    -2624.026
  Info: Results
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkExecute.jl:15
  Info: Optimal solution: 8 signals
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkExecute.jl:20
Signals:  2 Fit:     32.70151 Silhouette:            1 AIC:    -2276.215
Signals:  3 Fit:      24.6022 Silhouette:    0.9999996 AIC:    -2377.607
Signals:  4 Fit:     18.46274 Silhouette:    0.9999994 AIC:    -2480.975
Signals:  5 Fit:     14.74592 Silhouette:     0.764538 AIC:    -2535.007
Signals:  6 Fit:      12.3538 Silhouette:   -0.1423047 AIC:    -2551.193
Signals:  7 Fit:     10.29325 Silhouette:   -0.0733191 AIC:    -2571.714
Signals:  8 Fit:     8.237522 Silhouette:    0.2518114 AIC:    -2624.163
Signals:  9 Fit:     7.607165 Silhouette:  -0.07981342 AIC:    -2563.213
Signals: 10 Fit:     6.023938 Silhouette:   0.02130362 AIC:    -2624.026
  Info: Optimal solution: 8 signals
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkIO.jl:30
```

Here, the **NMFk** results are loaded from a prior ML runs.

As seen from the output above, the NMFk analyses identified that the optimal number of geothermal signatures in the dataset **8**.

Solutions with a number of signatures less than **8** are underfitting.

Solutions with a number of signatures greater than **8** are overfitting and unacceptable.

The set of accetable solutions are defined as follows:

[13]:
```
NMFk.getks(nkrange, robustness[nkrange])
```

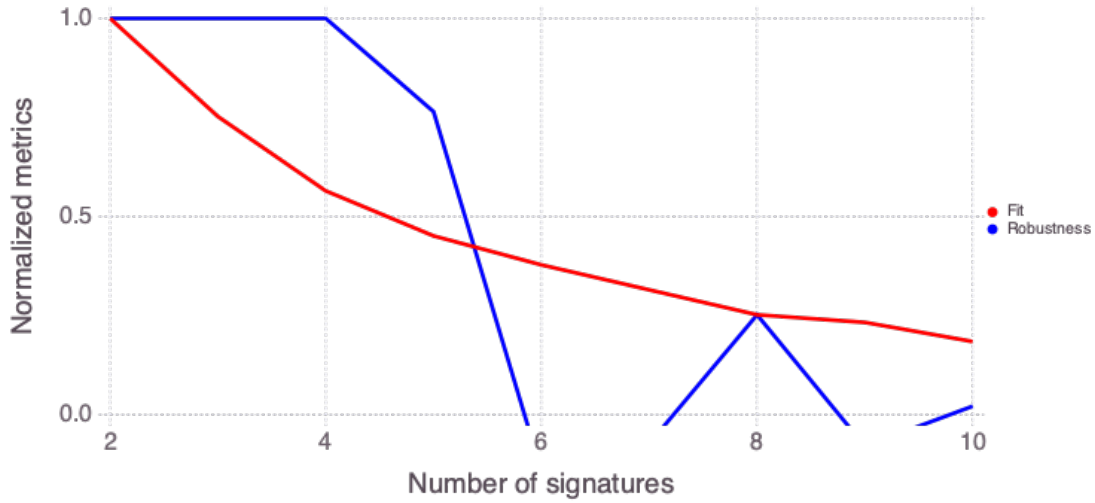
[13]:
```
5-element Array{Int64,1}:
 2
 3
 4
 5
 8
```

The accceptable solutions contain 2, 3, 4, 5 and 8 signatures.

0.4.1 Post-process NMFk results

Number of signatures Plot representing solution quality (fit) and silhouette width (robustness) for different number of sigantures `k`:

[14]:
```
NMFk.plot_signal_selecton(nkrange, fitquality, robustness; figuredir=figuredir,␣
↪xtitle="Number of signatures")
```



The plot above also demonstrates that the accceptable solutions contain 2, 3, 4, 5 and 8 signatures.

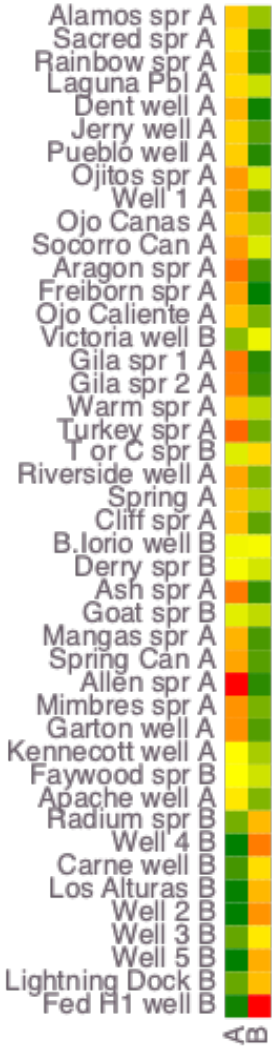
Analysis of all the accceptable solutions The ML solutions containing an acceptable number of signatures are further analyzed as follows:

[15]:
```
NMFk.clusterresults(NMFk.getks(nkrange, robustness[nkrange]), W, H, attributes,␣
↪locations; lat=lat, lon=lon, resultdir=resultdir, figuredir=figuredir,␣
↪Hcasefilename="locations", Wcasefilename="attributes");
```

```
Signal importance (high->low): [1, 2]
  Info: Number of signals: 2
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:144
  Info: Locations (signals=2)
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:148
  Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
  @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697

29×2 Array{Any,2}:
 "Allen spr"       1.0
```

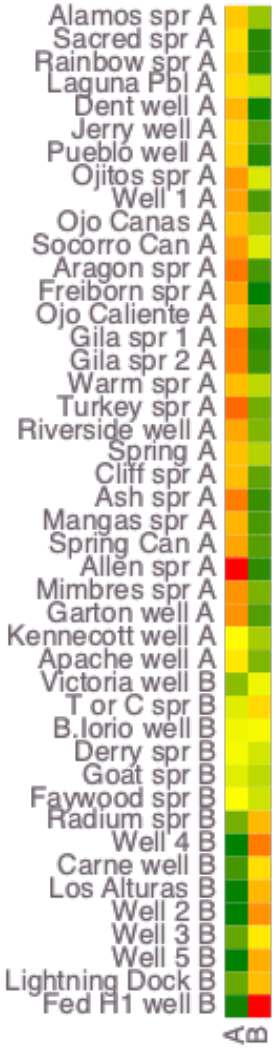
```
 "Turkey spr"      0.884139
 "Aragon spr"      0.849368
 "Gila spr 1"      0.845807
 "Ash spr"         0.839107
 "Gila spr 2"      0.829838
 "Garton well"     0.788626
 "Mimbres spr"     0.7852
 "Ojitos spr"      0.76979
 "Socorro Can"     0.761215
 "Freiborn spr"    0.745613
 "Well 1"          0.743076
 "Spring Can"      0.741828

 "Warm spr"        0.676919
 "Cliff spr"       0.676442
 "Ojo Caliente"    0.670285
 "Spring"          0.669871
 "Alamos spr"      0.64752
 "Pueblo well"     0.63547
 "Rainbow spr"     0.635234
 "Jerry well"      0.622338
 "Laguna Pbl"      0.601675
 "Sacred spr"      0.597838
 "Apache well"     0.563514
 "Kennecott well"  0.510178
```

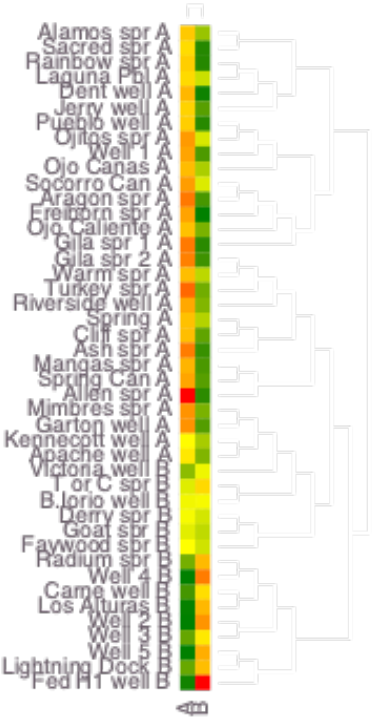
```
15×2 Array{Any,2}:
 "Fed H1 well"     1.0
 "Well 4"          0.840281
 "Well 2"          0.78384
 "Well 5"          0.719246
 "Los Alturas"     0.692025
 "Radium spr"      0.687742
 "Lightning Dock"  0.677317
 "T or C spr"      0.60486
 "Carne well"      0.592351
 "Well 3"          0.56113
 "B.Iorio well"    0.480433
 "Victoria well"   0.462937
 "Derry spr"       0.400573
 "Faywood spr"     0.391769
 "Goat spr"        0.354929
```

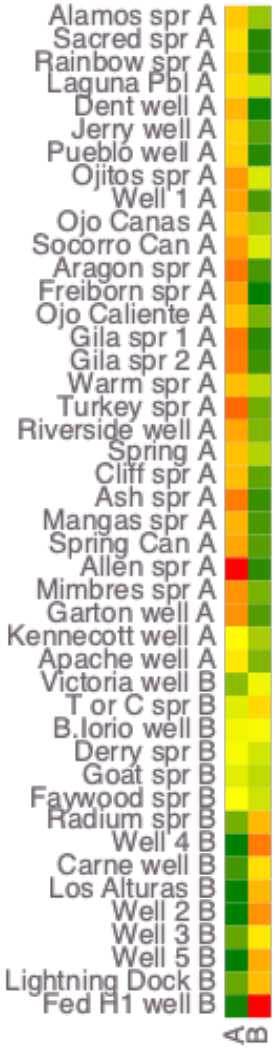


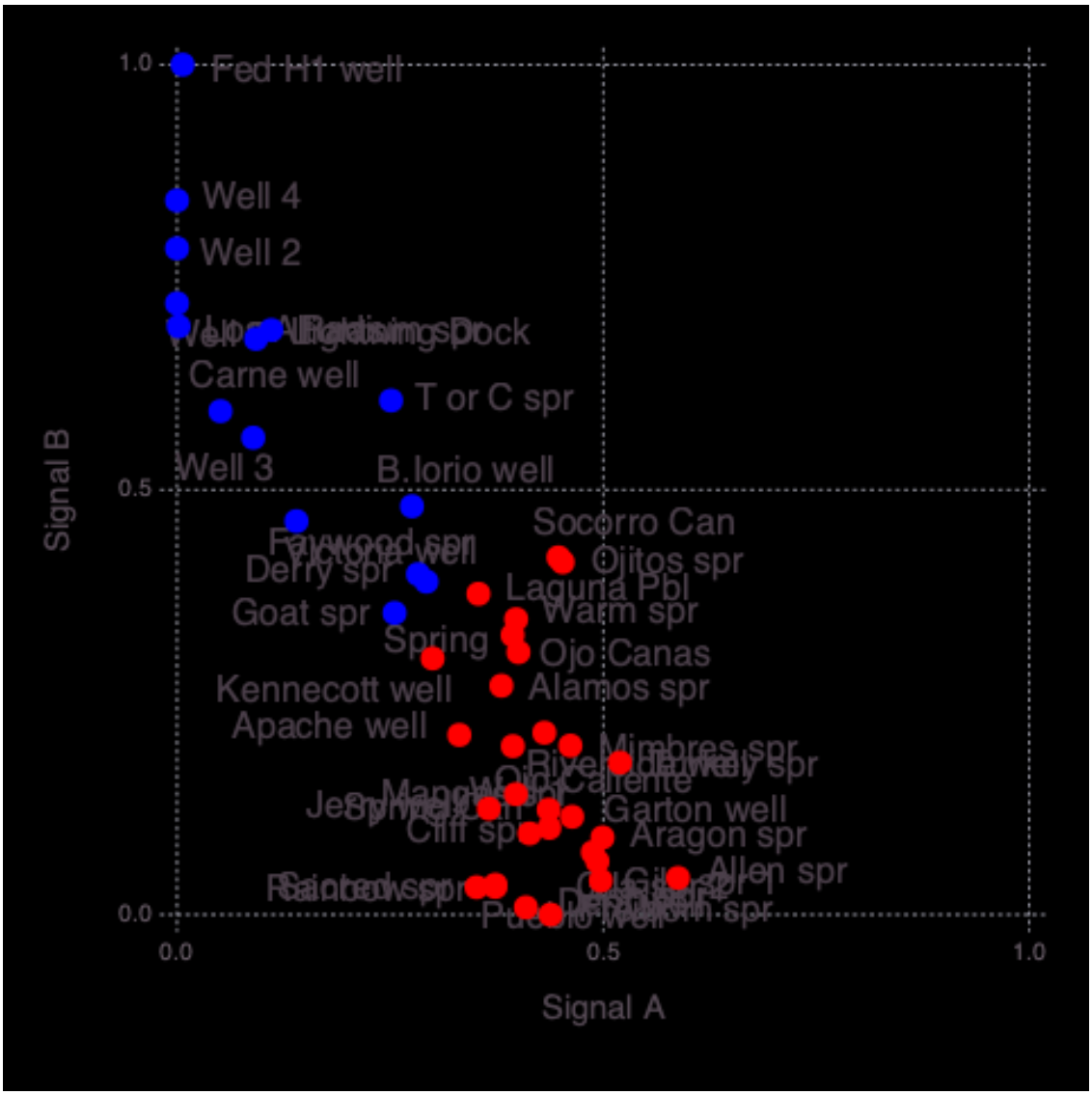

```
  Info: Robust k-means analysis results are loaded from file results-
case01/Hmatrix-2-2_44-1000.jld!
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
  @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
  Info: Robust k-means analysis results are loaded from file results-
case01/Wmatrix-2-2_18-1000.jld!
```

```
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
Info: Signal A -> A Count: 29
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
Info: Signal B -> B Count: 15
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
Info: Signal A (S1) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
Info: Signal B (S2) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
```



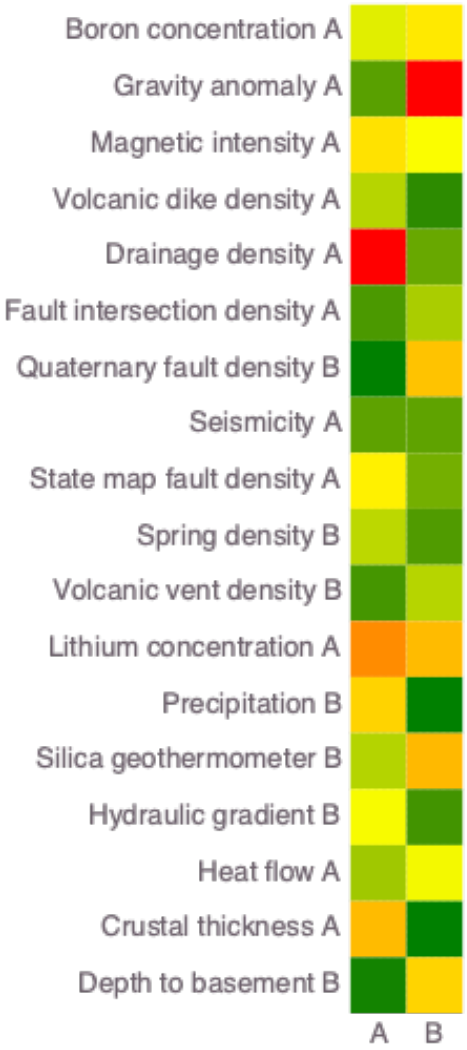

Alamos spr A
Sacred spr A
Rainbow spr A
Laguna Pb A
Dent well A
Jerry well A
Pueblo well A
Ojitos spr A
Well 1 A
Ojo Canas A
Socorro Can A
Aragon spr A
Freiborn spr A
Ojo Caliente A
Gila spr 1 A
Gila spr 2 A
Warm spr A
Turkey spr A
Riverside well A
Spring A
Cliff spr A
Ash spr A
Mangas spr A
Spring Can A
Allen spr A
Mimbres spr A
Garton well A
Kennecott well A
Apache well A
Victoria well B
T or C spr B
B.Iorio well B
Derry spr B
Goat spr B
Faywood spr B
Radium spr B
Well 4 B
Came well B
Los Alturas B
Well 2 B
Well 3 B
Well 5 B
Lightning Dock B
Fed H1 well B


Alamos spr A
Sacred spr A
Rainbow spr A
Laguna Pbl A
Dent well A
Jerry well A
Pueblo well A
Ojitos spr A
Well 1 A
Ojo Canas A
Socorro Can A
Aragon spr A
Freiborn spr A
Ojo Caliente A
Gila spr 1 A
Gila spr 2 A
Warm spr A
Turkey spr A
Riverside well A
Spring A
Cliff spr A
Ash spr A
Mangas spr A
Spring Can A
Allen spr A
Mimbres spr A
Garton well A
Kennecott well A
Apache well A
Victoria well B
T or C spr B
B.Iorio well B
Derry spr B
Goat spr B
Faywood spr B
Radium spr B
Well 4 B
Carne well B
Los Alturas B
Well 2 B
Well 3 B
Well 5 B
Lightning Dock B
Fed H1 well B
A
B



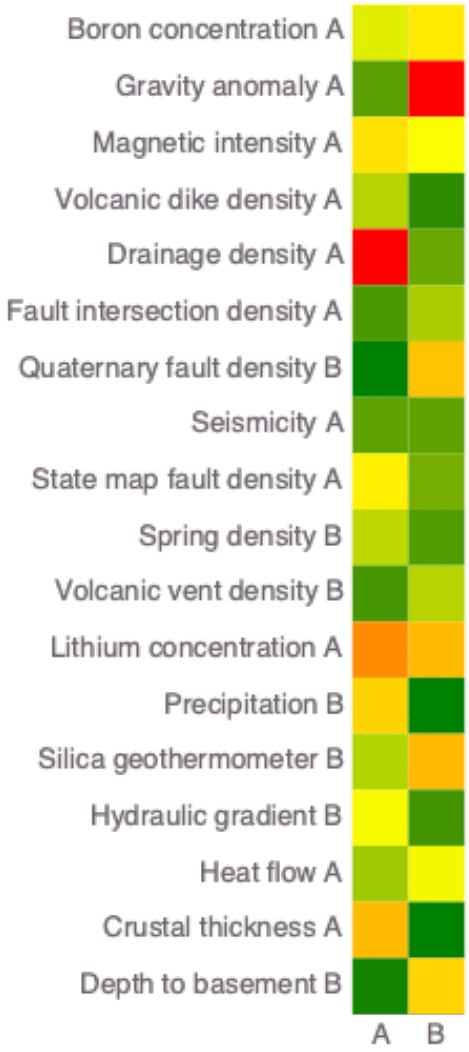

```
11×2 Array{Any,2}:
 "Drainage density"            1.0
 "Lithium concentration"       0.801888
 "Crustal thickness"           0.684456
 "Magnetic intensity"          0.581662
 "State map fault density"     0.539332
 "Boron concentration"         0.431691
 "Volcanic dike density"       0.334325
 "Heat flow"                   0.283606
 "Seismicity"                  0.13724
 "Gravity anomaly"             0.126086
 "Fault intersection density"  0.097643
```

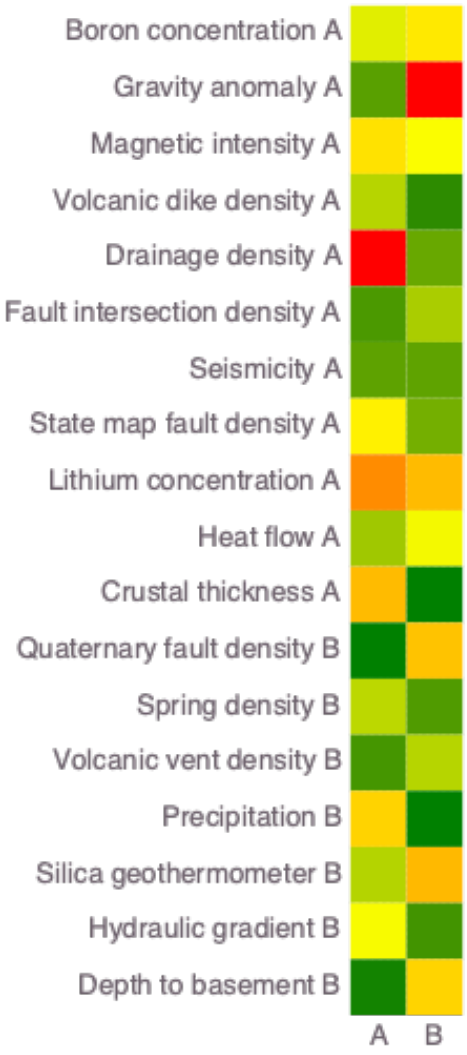
```
7×2 Array{Any,2}:
 "Silica geothermometer"     0.690981
 "Quaternary fault density"  0.664186
 "Depth to basement"         0.61722
 "Volcanic vent density"     0.334398
 "Spring density"            0.108699
 "Hydraulic gradient"        0.0811159
 "Precipitation"             0.0
```

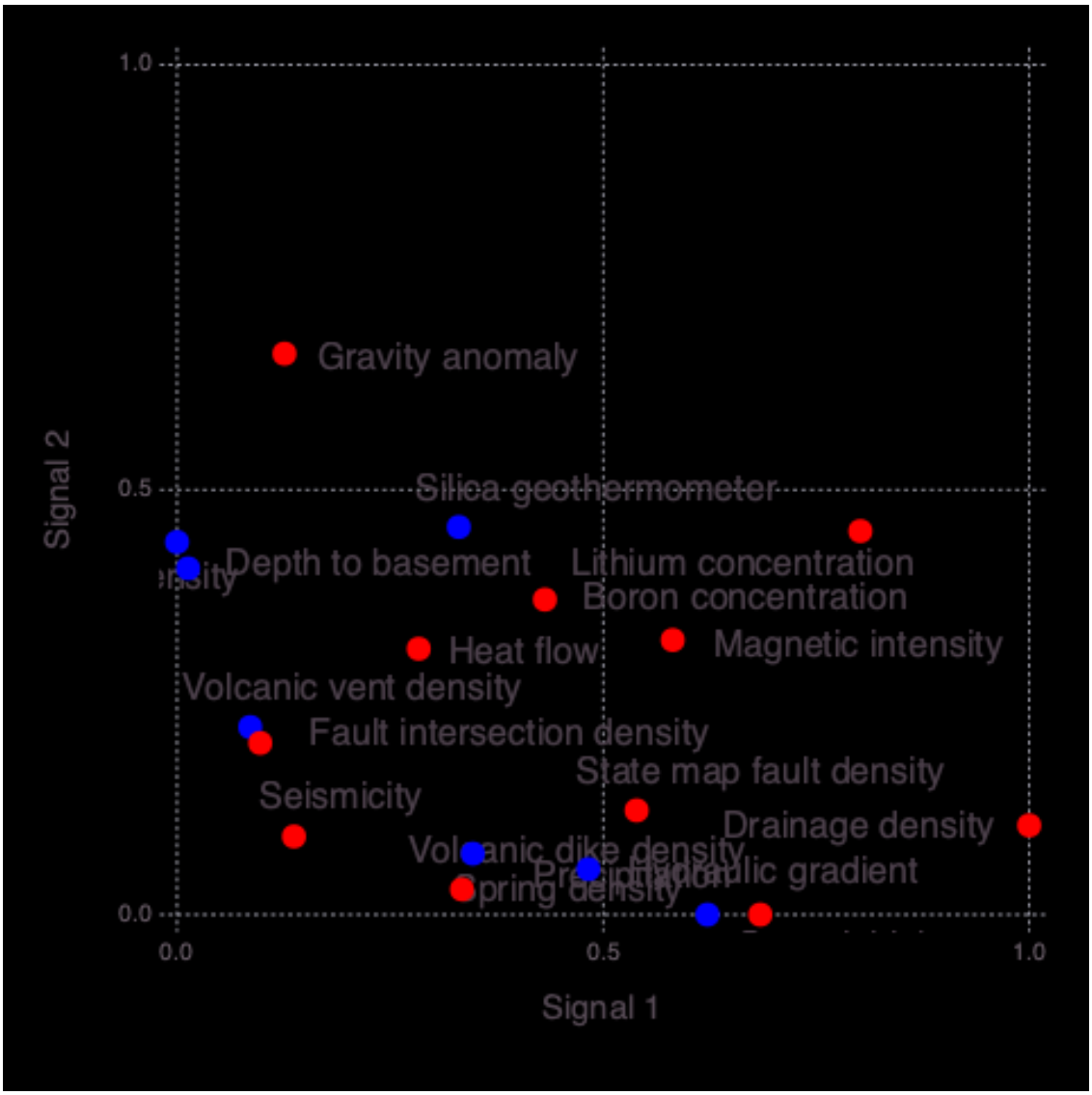


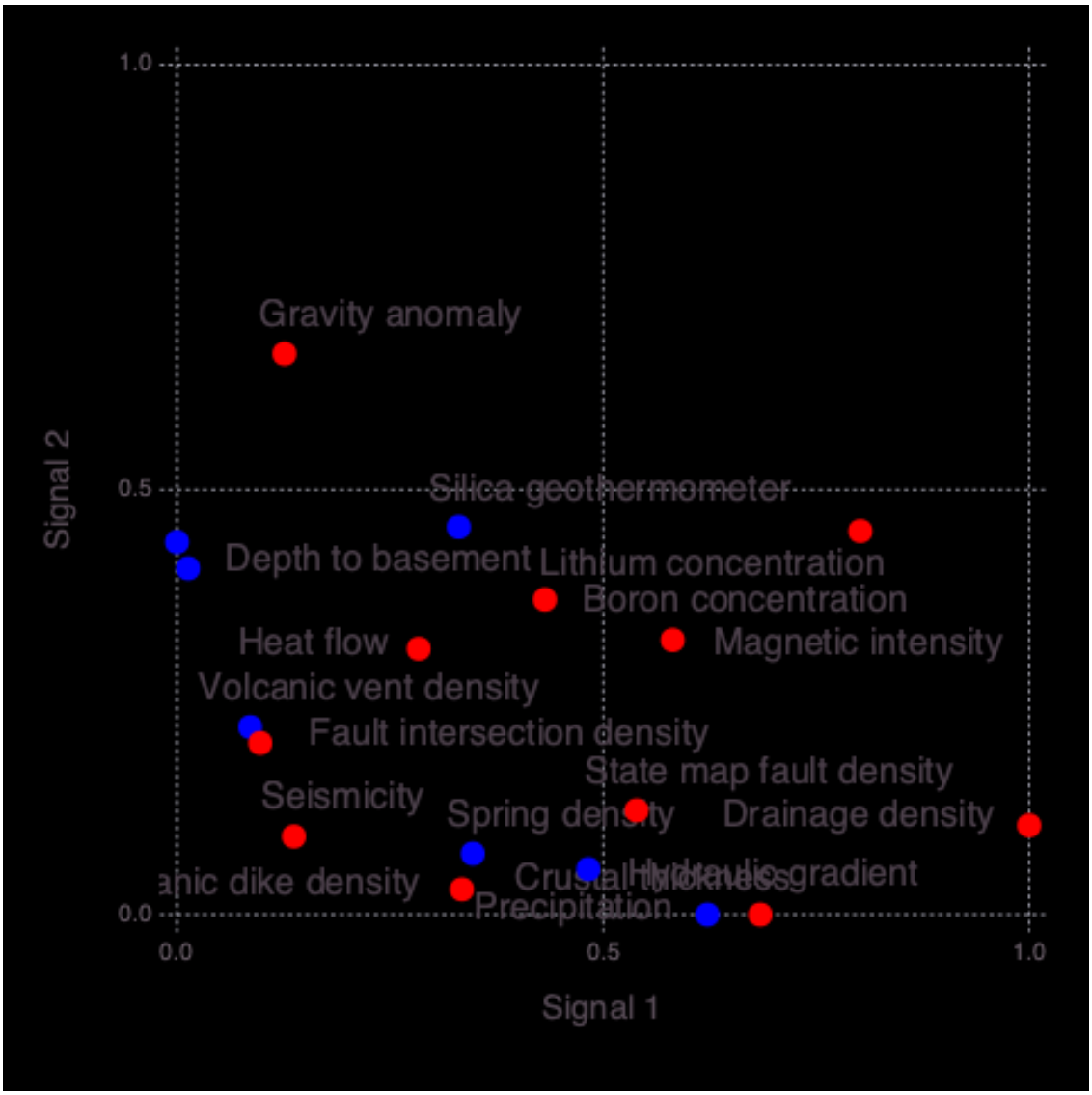

```
 Info: Attributes (signals=2)
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:322
 Info: Signal A (S1) Count: 11
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
 Info: Signal B (S2) Count: 7
```

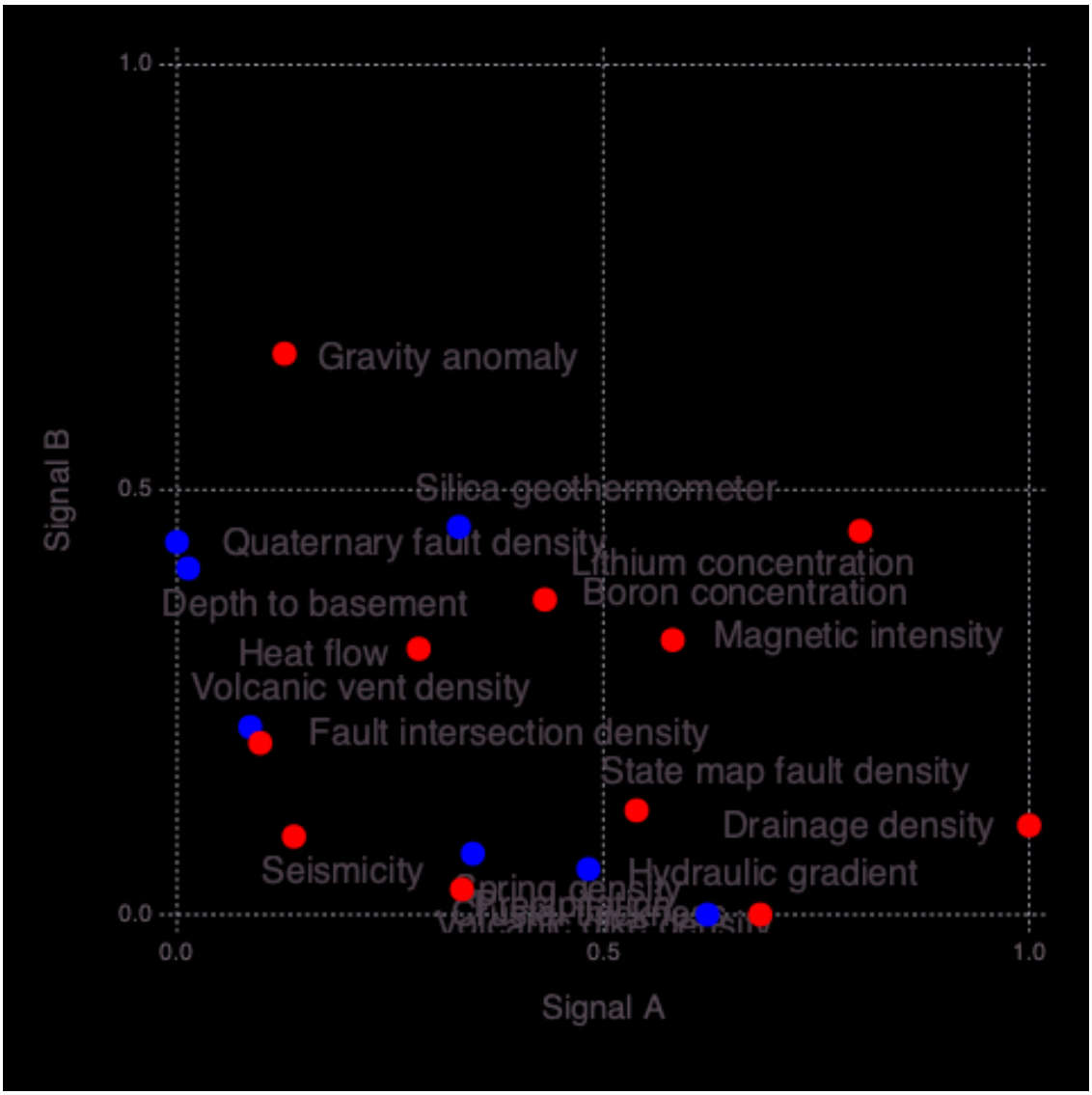
```
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal A -> A Count: 11
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal B -> B Count: 7
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal A (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal B (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
```

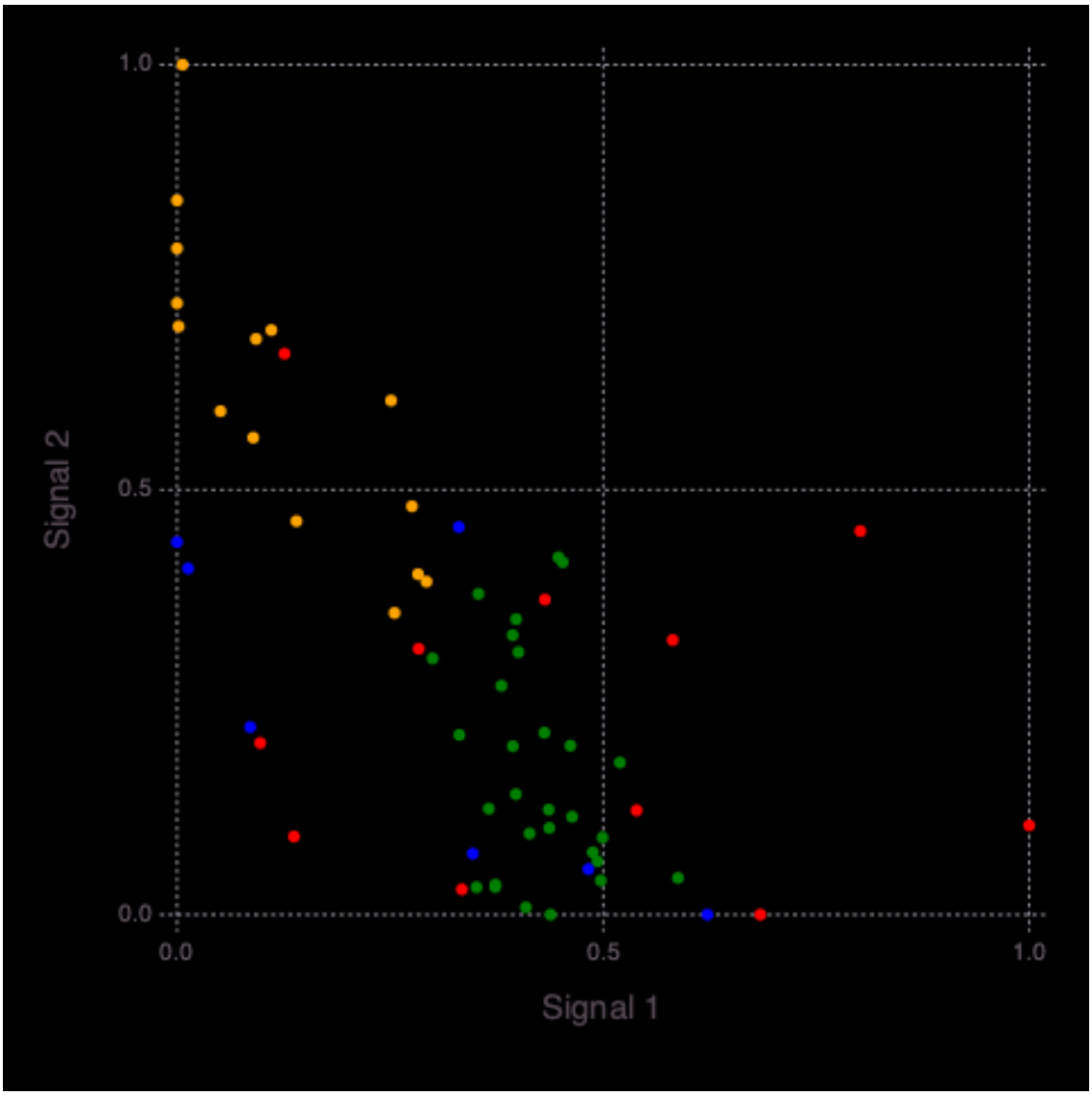



Boron concentration A
Gravity anomaly A
Magnetic intensity A
Volcanic dike density A
Drainage density A
Fault intersection density A
Seismicity A
State map fault density A
Lithium concentration A
Heat flow A
Crustal thickness A
Quaternary fault density B
Spring density B
Volcanic vent density B
Precipitation B
Silica geothermometer B
Hydraulic gradient B
Depth to basement B
A
B


1.0
0.5
0.0
0.0
0.5
1.0
Signal 2
Signal 1
Gravity anomaly
Silica geothermometer
Depth to basement
Lithium concentration
Boron concentration
Heat flow
Magnetic intensity
Volcanic vent density
Fault intersection density
State map fault density
Seismicity
Drainage density
Volcanic dike density
Spring density


1.0
0.5
0.0
0.0
0.5
1.0
Signal 2
Signal 1
Gravity anomaly
Silica geothermometer
Depth to basement
Lithium concentration
Boron concentration
Heat flow
Magnetic intensity
Volcanic vent density
Fault intersection density
State map fault density
Seismicity
Spring density
Drainage density
Hydraulic gradient
Precipitation

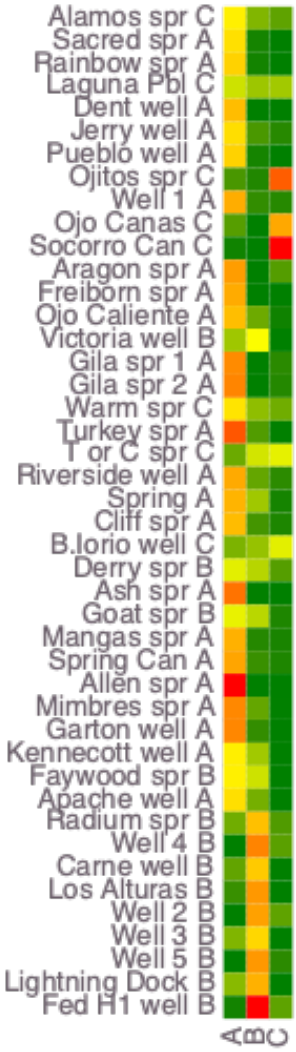

1.0
0.5
0.0
0.0
0.5
1.0
Signal B
Signal A
Gravity anomaly
Silica geothermometer
Quaternary fault density
Lithium concentration
Boron concentration
Depth to basement
Magnetic intensity
Heat flow
Volcanic vent density
Fault intersection density
State map fault density
Drainage density
Seismicity
Hydraulic gradient




```
Signal importance (high->low): [1, 2, 3]
  Info: Number of signals: 3
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:144
  Info: Locations (signals=3)
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:148
  Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
  @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
```

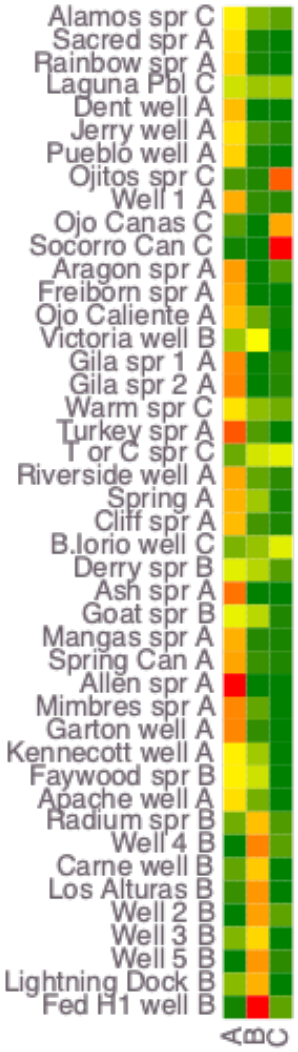
```
23×2 Array{Any,2}:
 "Allen spr"       1.0
 "Turkey spr"      0.916375
 "Ash spr"         0.86
```

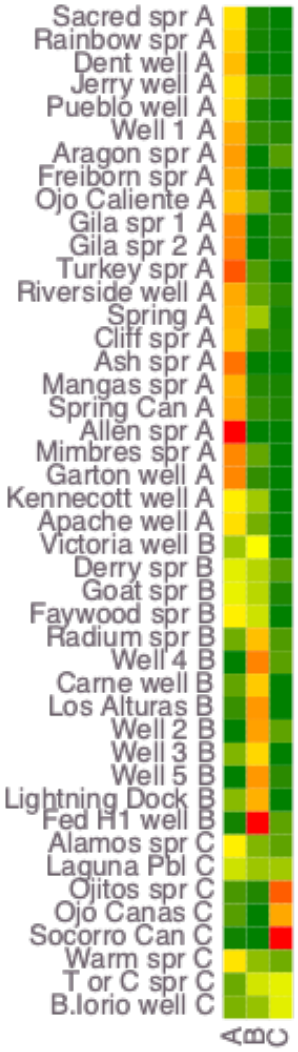
```
 "Gila spr 2"      0.81917
 "Garton well"     0.814428
 "Mimbres spr"     0.810983
 "Gila spr 1"      0.804735
 "Aragon spr"      0.760672
 "Spring Can"      0.74146
 "Riverside well"  0.729138
 "Freiborn spr"    0.726089
 "Well 1"          0.721013
 "Mangas spr"      0.710025
 "Spring"          0.702419
 "Cliff spr"       0.681147
 "Dent well"       0.67989
 "Ojo Caliente"    0.678069
 "Pueblo well"     0.624881
 "Rainbow spr"     0.623511
 "Jerry well"      0.59157
 "Apache well"     0.58789
 "Sacred spr"      0.586264
 "Kennecott well"  0.545995

13×2 Array{Any,2}:
 "Fed H1 well"     1.0
 "Well 4"          0.821925
 "Well 5"          0.773654
 "Los Alturas"     0.773565
 "Well 2"          0.752558
 "Lightning Dock"  0.71038
 "Radium spr"      0.671286
 "Carne well"      0.644475
 "Well 3"          0.610426
 "Victoria well"   0.492095
 "Faywood spr"     0.385637
 "Goat spr"        0.341865
 "Derry spr"       0.336225

8×2 Array{Any,2}:
 "Socorro Can"   1.0
 "Ojitos spr"    0.902801
 "Ojo Canas"     0.734799
 "T or C spr"    0.443392
 "B.Iorio well"  0.437021
 "Laguna Pbl"    0.288994
 "Warm spr"      0.177227
 "Alamos spr"    0.139853
```

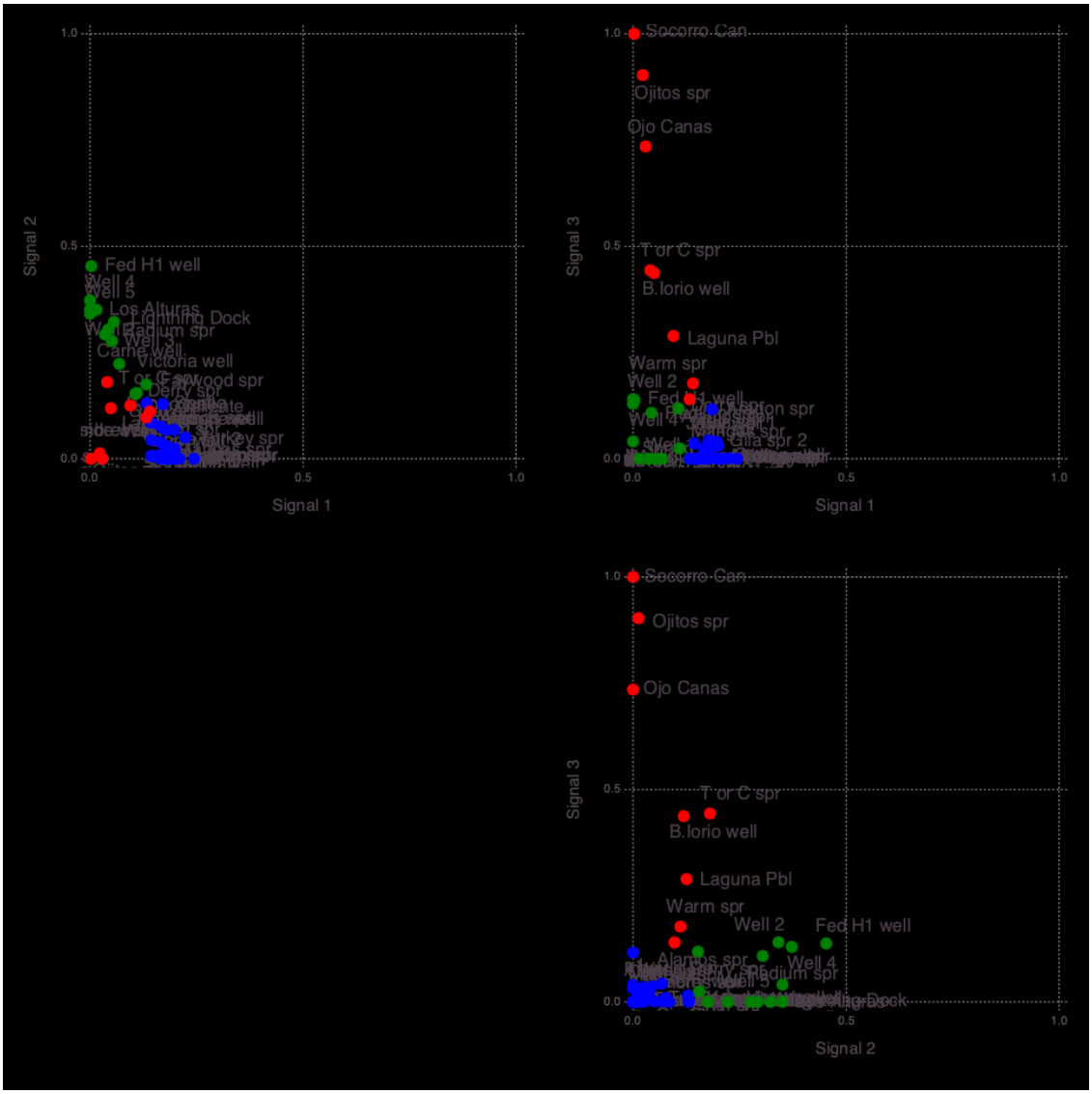


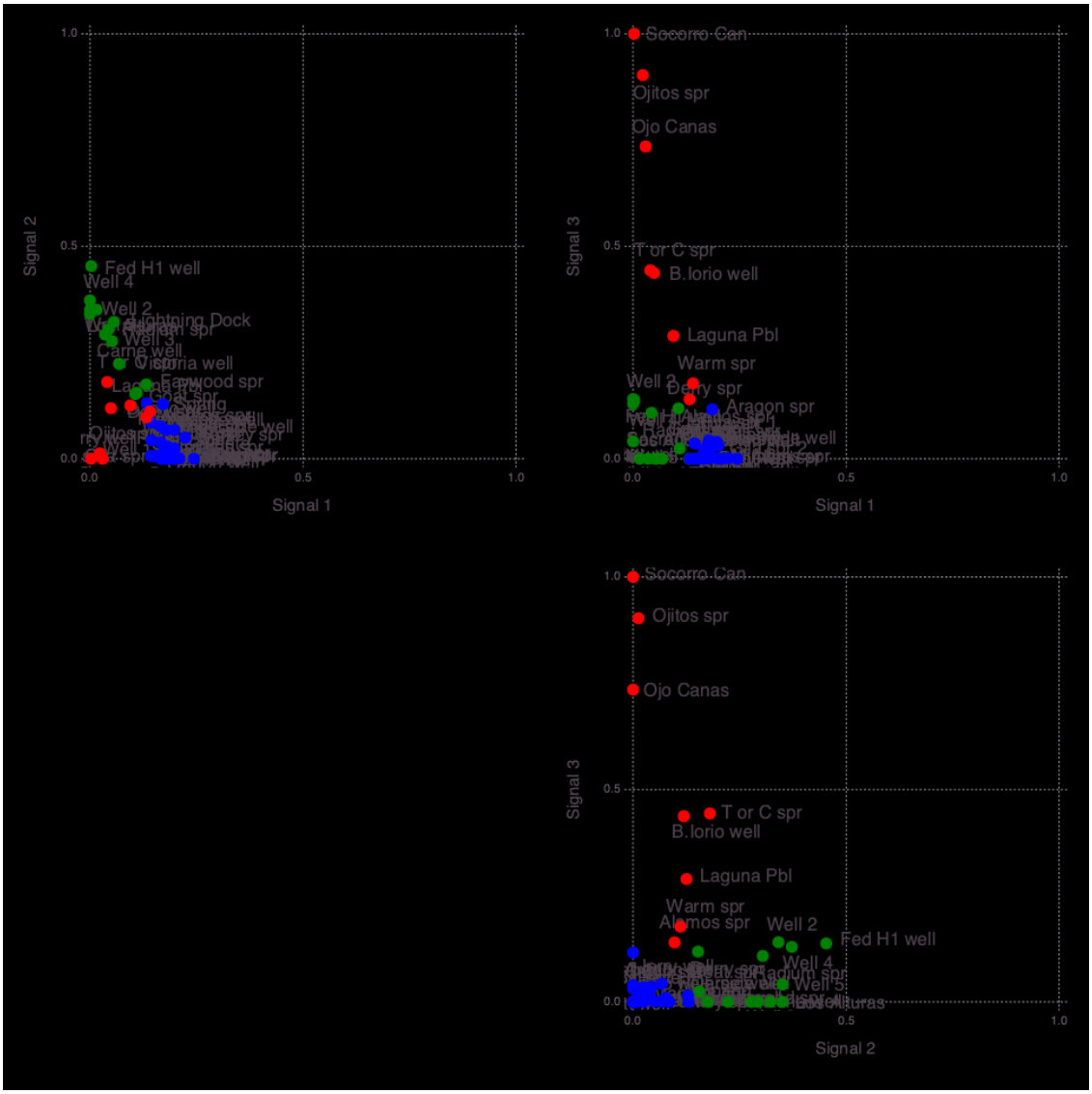

```
  Info: Robust k-means analysis results are loaded from file results-
case01/Hmatrix-3-3_44-1000.jld!
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
  @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
```

```
  Info: Robust k-means analysis results are loaded from file results-
case01/Wmatrix-3-3_18-1000.jld!
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Info: Signal A -> A Count: 23
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
  Info: Signal B -> B Count: 13
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
  Info: Signal C -> C Count: 8
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
  Info: Signal A (S1) (k-means clustering)
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
  Info: Signal B (S2) (k-means clustering)
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
  Info: Signal C (S3) (k-means clustering)
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
```


Alamos spr C
Sacred spr A
Rainbow spr A
Laguna Pbl C
Dent well A
Jerry well A
Pueblo well A
Ojitos spr C
Well 1 A
Ojo Canas C
Socorro Can C
Aragon spr A
Freiborn spr A
Ojo Caliente A
Victoria well B
Gila spr 1 A
Gila spr 2 A
Warm spr C
Turkey spr A
T or C spr C
Riverside well A
Spring A
Cliff spr A
B.Iorio well C
Derry spr B
Ash spr A
Goat spr B
Mangas spr A
Spring Can A
Allen spr A
Mimbres spr A
Garton well A
Kennecott well A
Faywood spr B
Apache well A
Radium spr B
Well 4 B
Carne well B
Los Alturas B
Well 2 B
Well 3 B
Well 5 B
Lightning Dock B
Fed H1 well B
A
B
C


Sacred spr A
Rainbow spr A
Dent well A
Jerry well A
Pueblo well A
Well 1 A
Aragon spr A
Freiborn spr A
Ojo Caliente A
Gila spr 1 A
Gila spr 2 A
Turkey spr A
Riverside well A
Spring A
Cliff spr A
Ash spr A
Mangas spr A
Spring Can A
Allen spr A
Mimbres spr A
Garton well A
Kennecott well A
Apache well A
Victoria well B
Derry spr B
Goat spr B
Faywood spr B
Radium spr B
Well 4 B
Carne well B
Los Alturas B
Well 2 B
Well 3 B
Well 5 B
Lightning Dock B
Fed H1 well B
Alamos spr C
Laguna Pbl C
Ojitos spr C
Ojo Canas C
Socorro Can C
Warm spr C
T or C spr C
B.Iorio well C
A
B
C

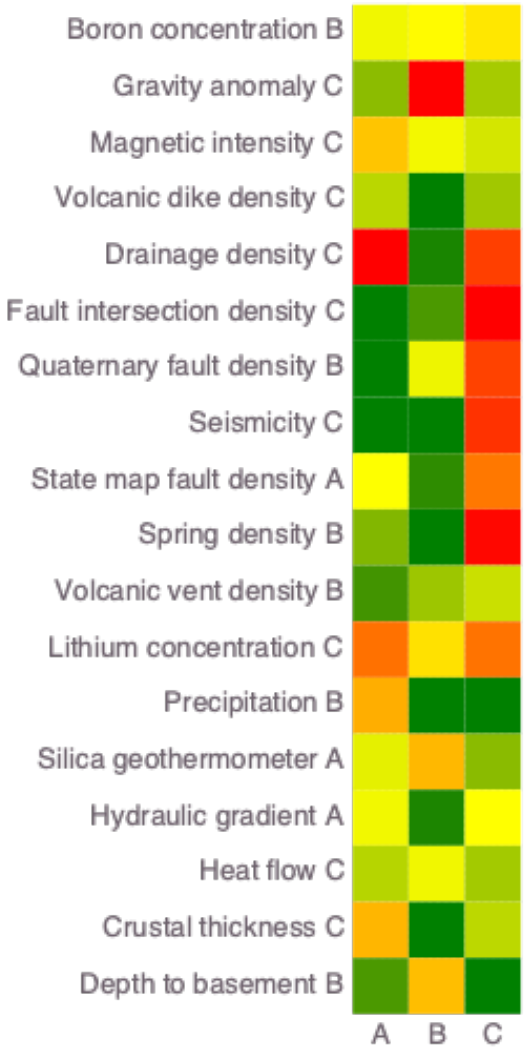

Signal 2
Signal 1
Fed H1 well
Well 4
Well 5
Los Alturas
Lightning Dock
Radium spr
Well 3
Carne well
Victoria well
T or C wood spr
Derry spr
Turkey spr
Signal 3
Signal 1
Socorro Can
Ojitos spr
Ojo Canas
T or C spr
B.lorio well
Laguna Pbl
Warm spr
Well 2
Fed H1 well
Well 4
Radium spr
Ella spr 2
Signal 3
Signal 2
Socorro Can
Ojitos spr
Ojo Canas
T or C spr
B.lorio well
Laguna Pbl
Warm spr
Well 2
Fed H1 well
Alamos spr
Well 4
Radium spr
Well 3
Lightning Dock




```
3×2 Array{Any,2}:
 "State map fault density"  0.496198
 "Hydraulic gradient"       0.469537
 "Silica geothermometer"    0.439841
```

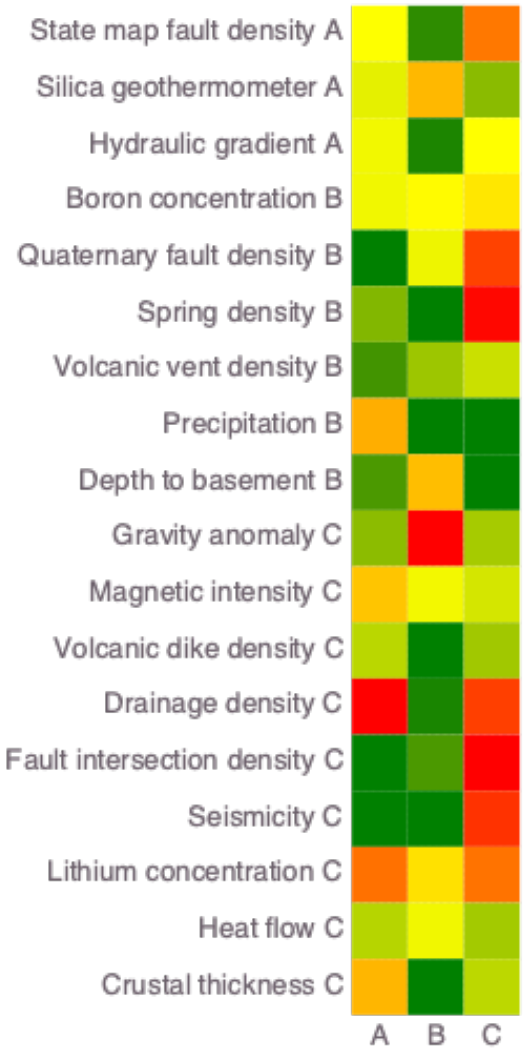
```
6×2 Array{Any,2}:
 "Depth to basement"          0.676939
 "Boron concentration"        0.511079
 "Quaternary fault density"   0.460437
 "Volcanic vent density"      0.27834
 "Spring density"             0.0
 "Precipitation"              0.0
```

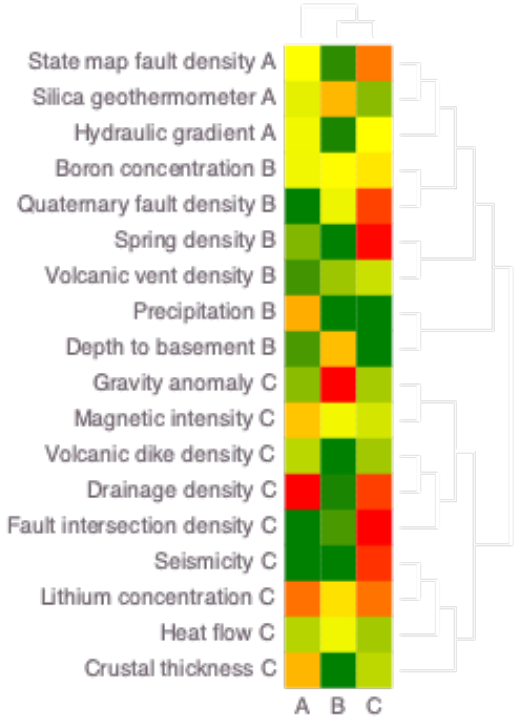
```
9×2 Array{Any,2}:
 "Fault intersection density"  1.0
 "Seismicity"                  0.967935
 "Drainage density"            0.952827
 "Lithium concentration"       0.858236
 "Magnetic intensity"          0.403114
 "Crustal thickness"           0.346896
 "Gravity anomaly"             0.297228
 "Heat flow"                   0.290886
 "Volcanic dike density"       0.28542
```

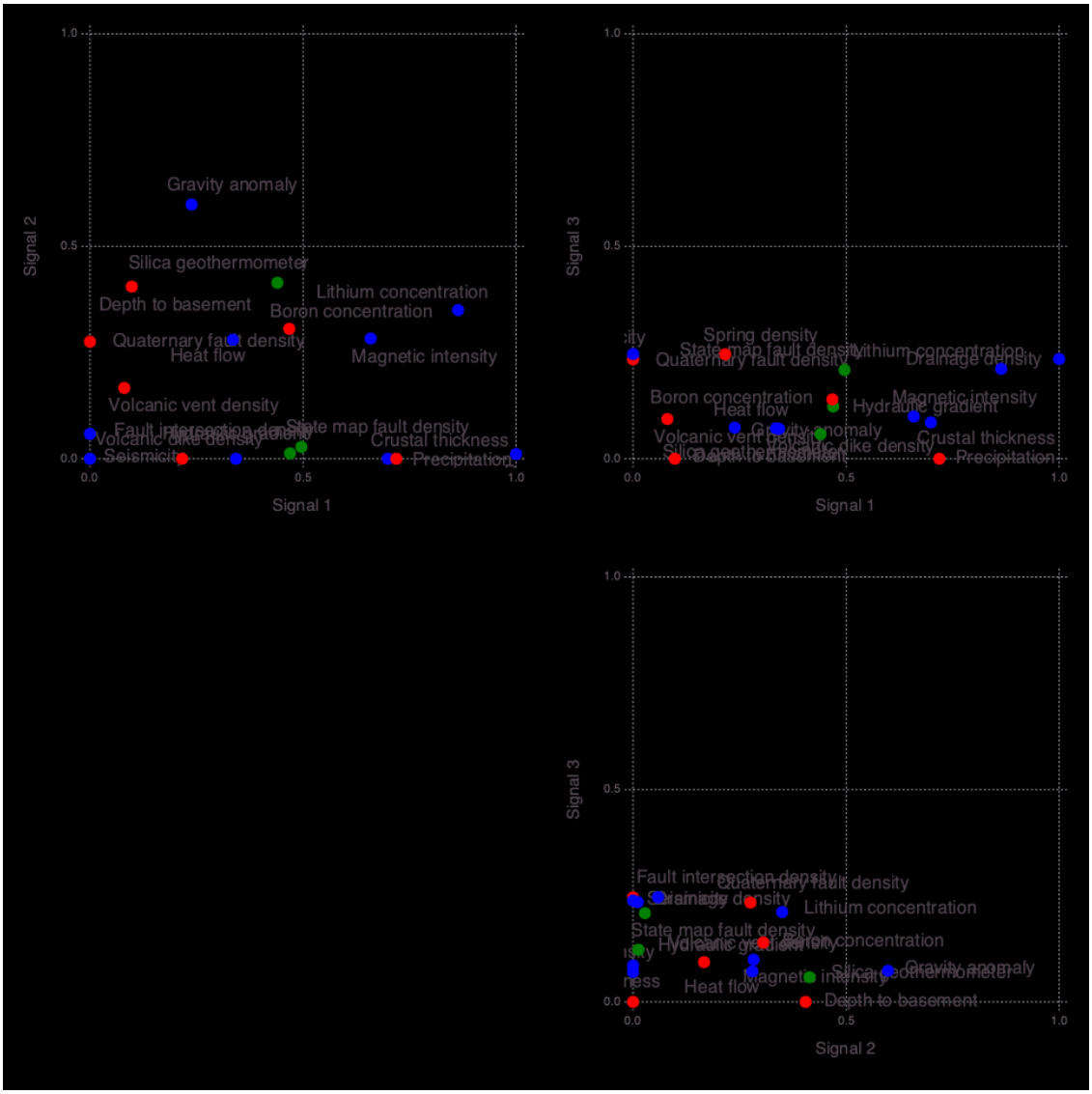


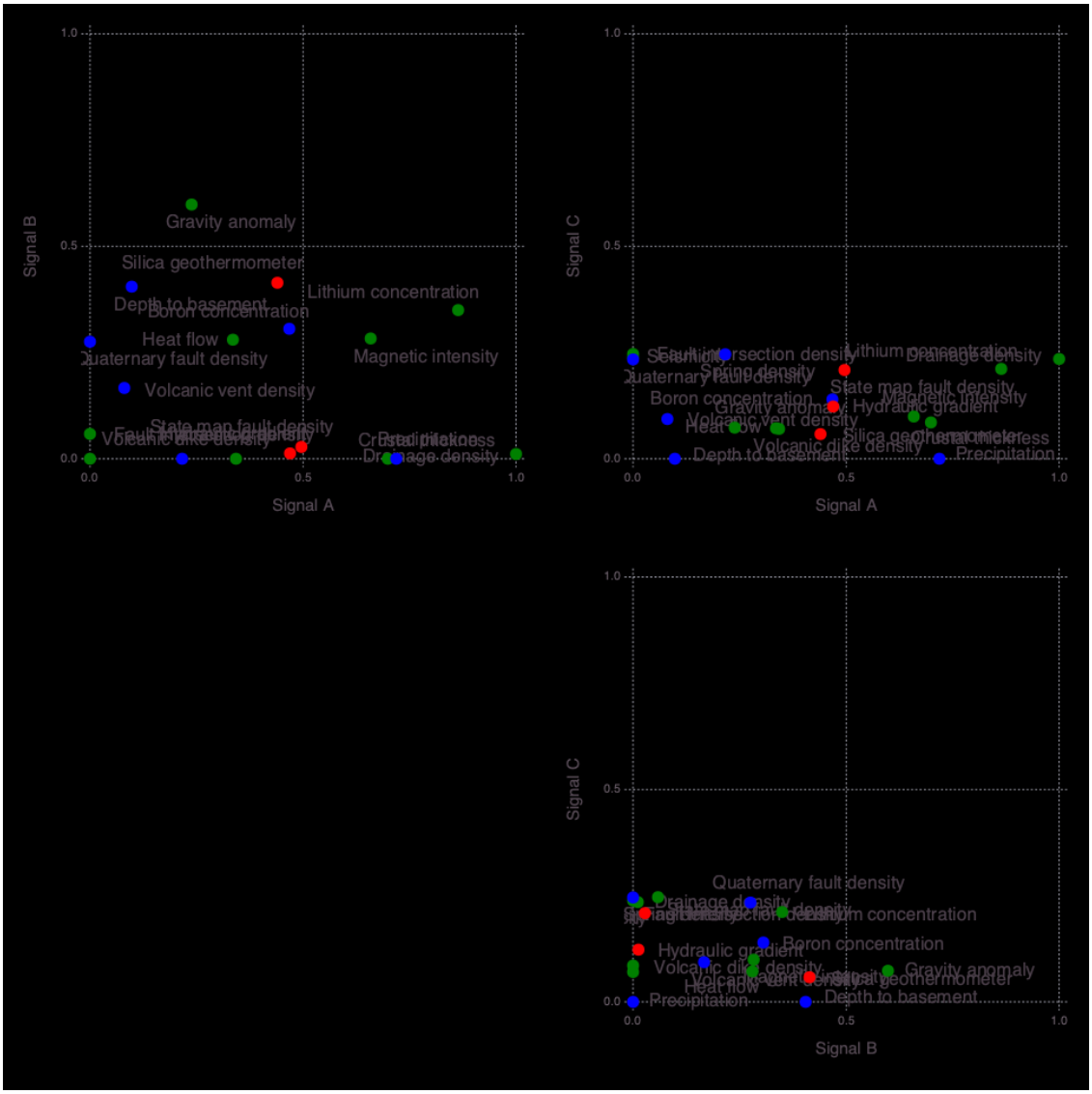

```
 Info: Attributes (signals=3)
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:322
 Info: Signal A (S3) Count: 9
```

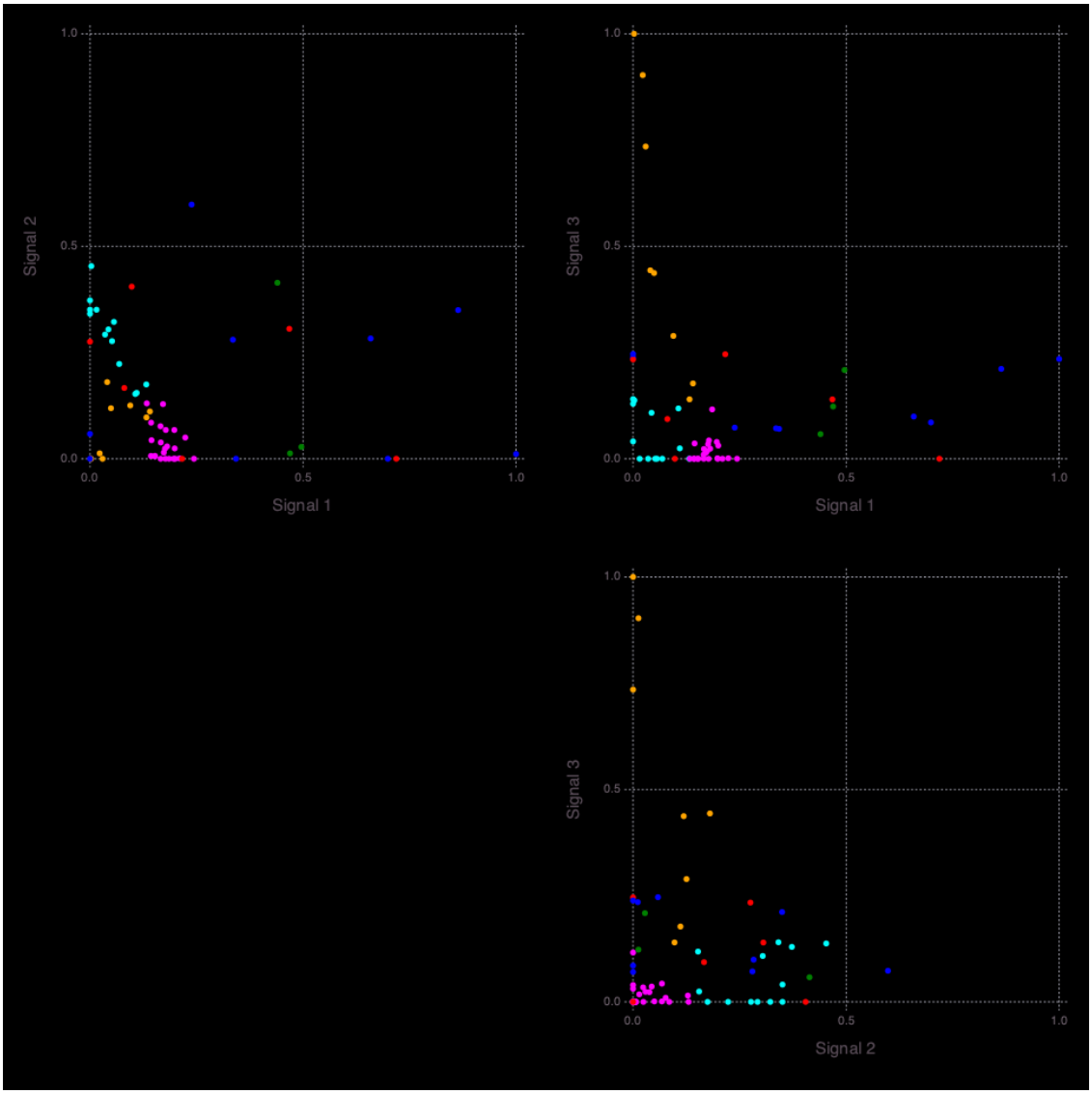
```
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal B (S2) Count: 6
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal C (S1) Count: 3
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal C -> A Count: 3
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal B -> B Count: 6
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal A -> C Count: 9
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal A (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal B (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal C (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
```

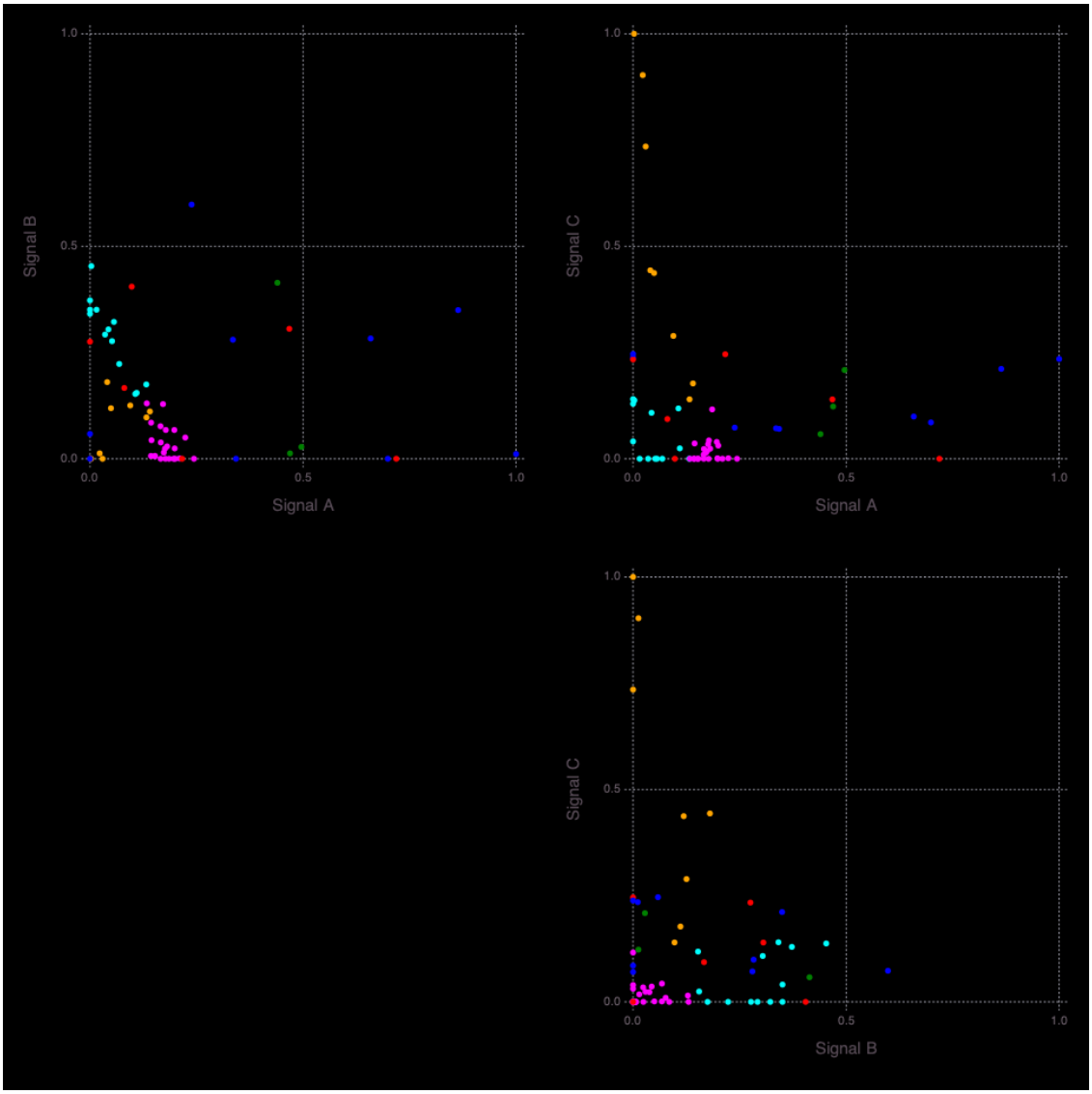

State map fault density A
Silica geothermometer A
Hydraulic gradient A
Boron concentration B
Quaternary fault density B
Spring density B
Volcanic vent density B
Precipitation B
Depth to basement B
Gravity anomaly C
Magnetic intensity C
Volcanic dike density C
Drainage density C
Fault intersection density C
Seismicity C
Lithium concentration C
Heat flow C
Crustal thickness C
A
B
C


State map fault density A
Silica geothermometer A
Hydraulic gradient A
Boron concentration B
Quaternary fault density B
Spring density B
Volcanic vent density B
Precipitation B
Depth to basement B
Gravity anomaly C
Magnetic intensity C
Volcanic dike density C
Drainage density C
Fault intersection density C
Seismicity C
Lithium concentration C
Heat flow C
Crustal thickness C
A
B
C


Signal 2
Signal 1
Gravity anomaly
Silica geothermometer
Depth to basement
Lithium concentration
Boron concentration
Quaternary fault density
Heat flow
Magnetic intensity
Volcanic vent density
Crustal thickness
Precipitation
Signal 3
Signal 1
Spring density
Drainage density
Boron concentration
Heat flow
Hydraulic gradient
Magnetic intensity
Crustal thickness
Precipitation
Signal 3
Signal 2
Fault intersection density
Quaternary fault density
Lithium concentration
State map fault density
Heat flow
Gravity anomaly
Depth to basement


Signal B
Signal A
Gravity anomaly
Silica geothermometer
Lithium concentration
Depth to basement
Boron concentration
Heat flow
Magnetic intensity
Quaternary fault density
Volcanic vent density
State map fault density
Volcanic dike density
Crustal thickness
Precipitation
Drainage density
Signal C
Signal A
Lithium concentration
Drainage density
Spring density
Quaternary fault density
State map fault density
Boron concentration
Magnetic intensity
Gravity anomaly
Hydraulic gradient
Volcanic vent density
Heat flow
Silica geothermometer
Volcanic dike density
Depth to basement
Precipitation
Signal C
Signal B
Quaternary fault density
Drainage density
Boron concentration
Hydraulic gradient
Gravity anomaly
Heat flow
Depth to basement
Precipitation


1.0
0.5
0.0
Signal 2
0.0
0.5
1.0
Signal 1
1.0
0.5
0.0
Signal 3
0.0
0.5
1.0
Signal 1
1.0
0.5
0.0
Signal 3
0.0
0.5
1.0
Signal 2




```
Signal importance (high->low): [2, 1, 4, 3]
  Info: Number of signals: 4
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:144
  Info: Locations (signals=4)
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:148
  Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
  @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
```

```
15×2 Array{Any,2}:
 "Allen spr"       1.0
 "Turkey spr"      0.890671
 "Ash spr"         0.860399
```

```
 "Garton well"     0.837981
 "Mimbres spr"     0.756788
 "Spring"          0.727799
 "Mangas spr"      0.697281
 "Gila spr 1"      0.667903
 "Spring Can"      0.647347
 "Gila spr 2"      0.646943
 "Riverside well"  0.602983
 "Cliff spr"       0.592572
 "Freiborn spr"    0.579998
 "Apache well"     0.569518
 "Kennecott well"  0.546961
```

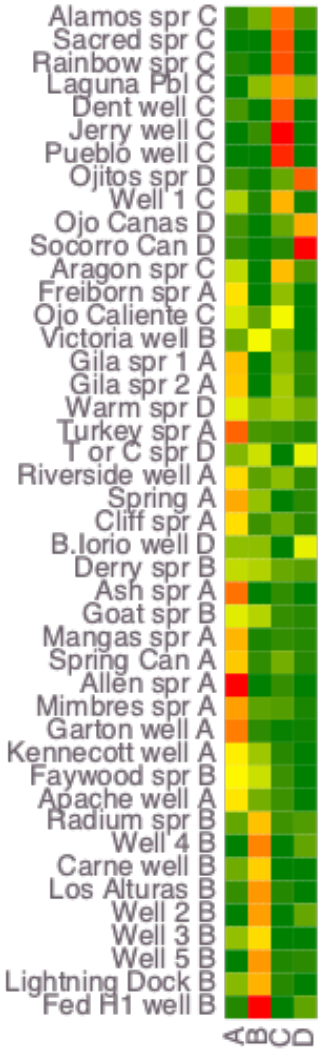
```
13×2 Array{Any,2}:
 "Fed H1 well"     1.0
 "Well 4"          0.820447
 "Los Alturas"     0.774358
 "Well 5"          0.771269
 "Well 2"          0.755708
 "Lightning Dock"  0.70557
 "Radium spr"      0.666575
 "Carne well"      0.631706
 "Well 3"          0.596359
 "Victoria well"   0.477645
 "Faywood spr"     0.378783
 "Goat spr"        0.330589
 "Derry spr"       0.324788
```

```
10×2 Array{Any,2}:
 "Jerry well"    1.0
 "Pueblo well"   0.978656
 "Rainbow spr"   0.926226
 "Sacred spr"    0.920803
 "Dent well"     0.911277
 "Alamos spr"    0.869018
 "Laguna Pbl"    0.779479
 "Well 1"        0.701792
 "Aragon spr"    0.678922
 "Ojo Caliente"  0.473437
```

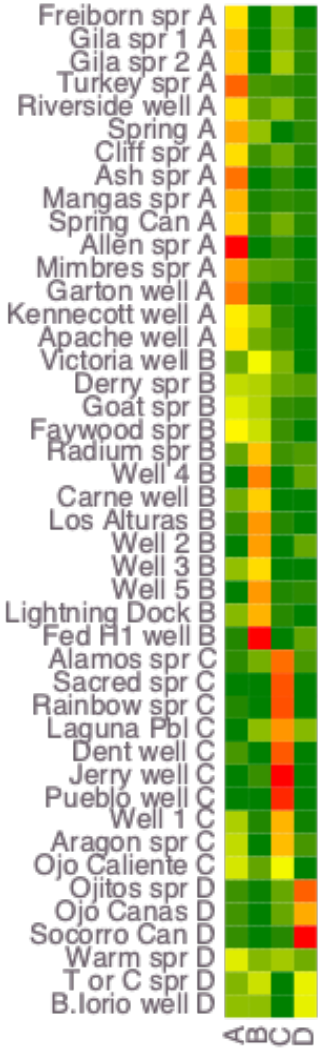
```
  Info: Robust k-means analysis results are loaded from file results-
case01/Hmatrix-4-4_44-1000.jld!
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
```

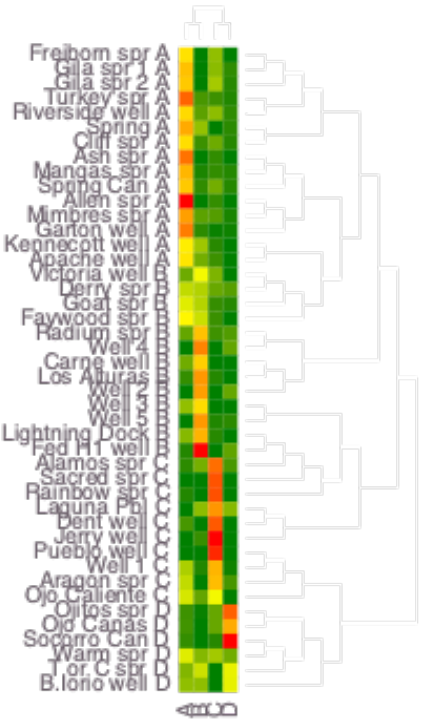
```
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
  @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
  Info: Robust k-means analysis results are loaded from file results-
case01/Wmatrix-4-4_18-1000.jld!
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
  Info: Signal A -> A Count: 15
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
  Info: Signal B -> B Count: 13
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
  Info: Signal C -> C Count: 10
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
  Info: Signal D -> D Count: 6
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
  Info: Signal A (S2) (k-means clustering)
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
  Info: Signal B (S1) (k-means clustering)
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
  Info: Signal C (S4) (k-means clustering)
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
```

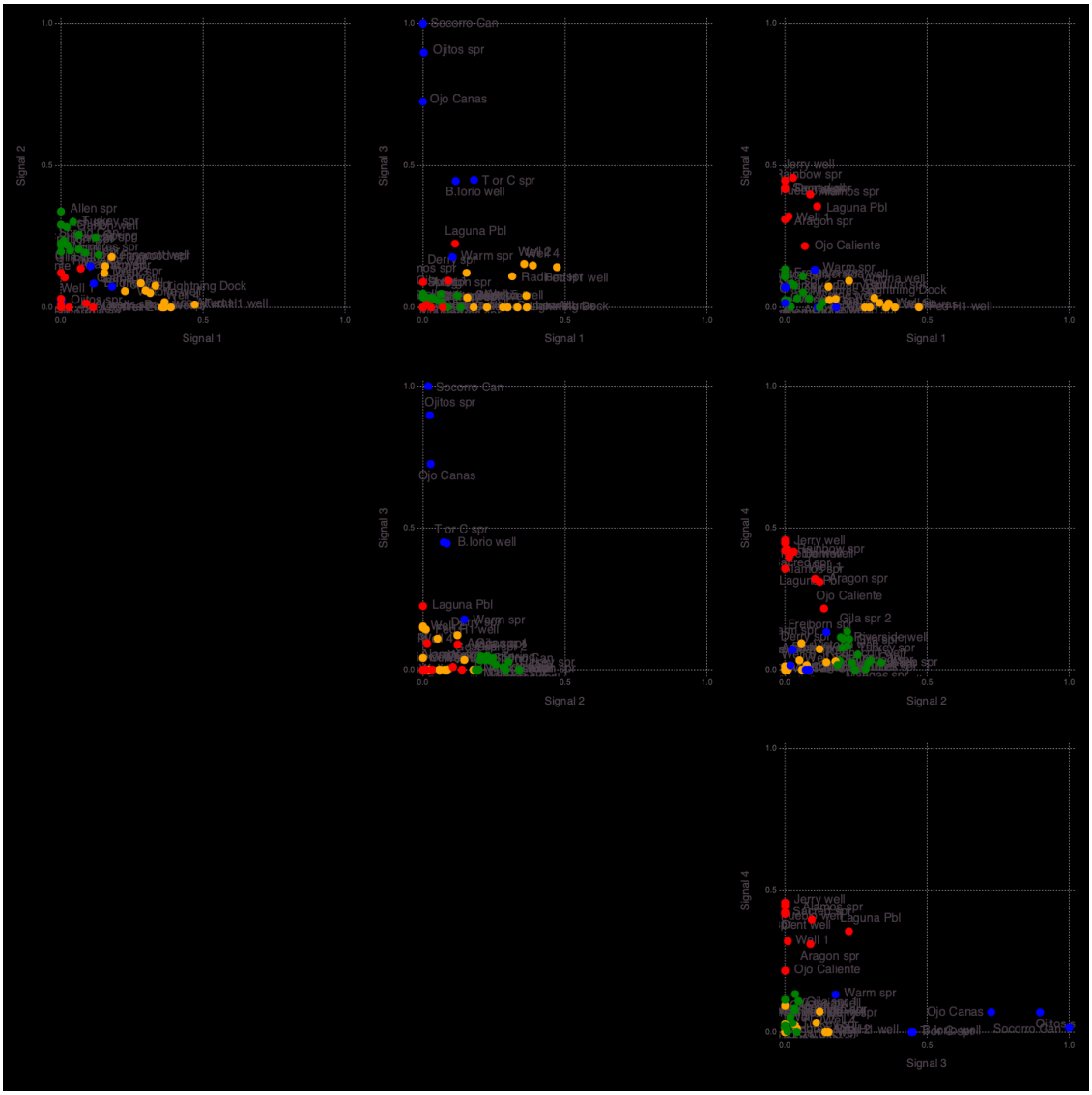
```
6×2 Array{Any,2}:
 "Socorro Can"   1.0
 "Ojitos spr"    0.897681
 "Ojo Canas"     0.725719
 "T or C spr"    0.449617
 "B.Iorio well"  0.445734
 "Warm spr"      0.177576
```

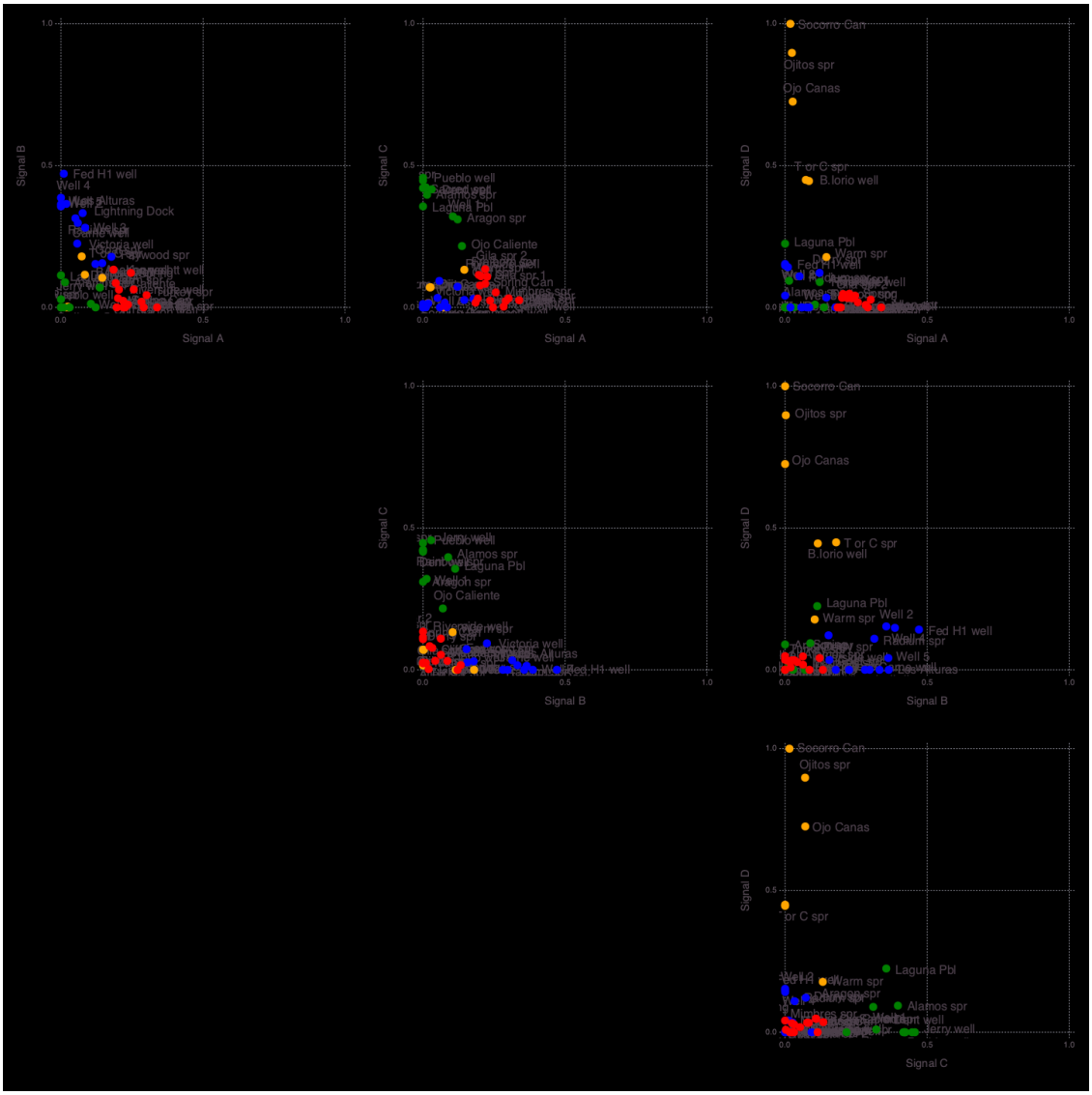



```
Info: Signal D (S3) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
```


Freiborn spr A
Gila spr 1 A
Gila spr 2 A
Turkey spr A
Riverside well A
Spring A
Cliff spr A
Ash spr A
Mangas spr A
Spring Can A
Allen spr A
Mimbres spr A
Garton well A
Kennecott well A
Apache well A
Victoria well B
Derry spr B
Goat spr B
Faywood spr B
Radium spr B
Well 4 B
Carne well B
Los Alturas B
Well 2 B
Well 3 B
Well 5 B
Lightning Dock B
Fed H1 well B
Alamos spr C
Sacred spr C
Rainbow spr C
Laguna Pbl C
Dent well C
Jerry well C
Pueblo well C
Well 1 C
Aragon spr C
Ojo Caliente C
Ojitos spr D
Ojo Canas D
Socorro Can D
Warm spr D
T or C spr D
B.Iorio well D
A
B
C
D


Freiborn spr A
Gila spr 1 A
Gila spr 2 A
Turkey spr A
Riverside well A
Spring A
Cliff spr A
Ash spr A
Mangas spr A
Spring Can A
Allen spr A
Mimbres spr A
Garton well A
Kennecott well A
Apache well A
Victoria well B
Derry spr B
Goat spr B
Faywood spr B
Radium spr B
Well 4 B
Carne well B
Los Alturas B
Well 2 B
Well 3 B
Well 5 B
Lightning Dock B
Fed H1 well B
Alamos spr C
Sacred spr C
Rainbow spr C
Laguna Pb C
Bent well C
Jerry well C
Pueblo well C
Well 1 C
Aragon spr C
Ojo Caliente C
Ojitos spr D
Ojo Canas D
Socorro Can D
Warm spr D
T or C spr D
B.lonio well D

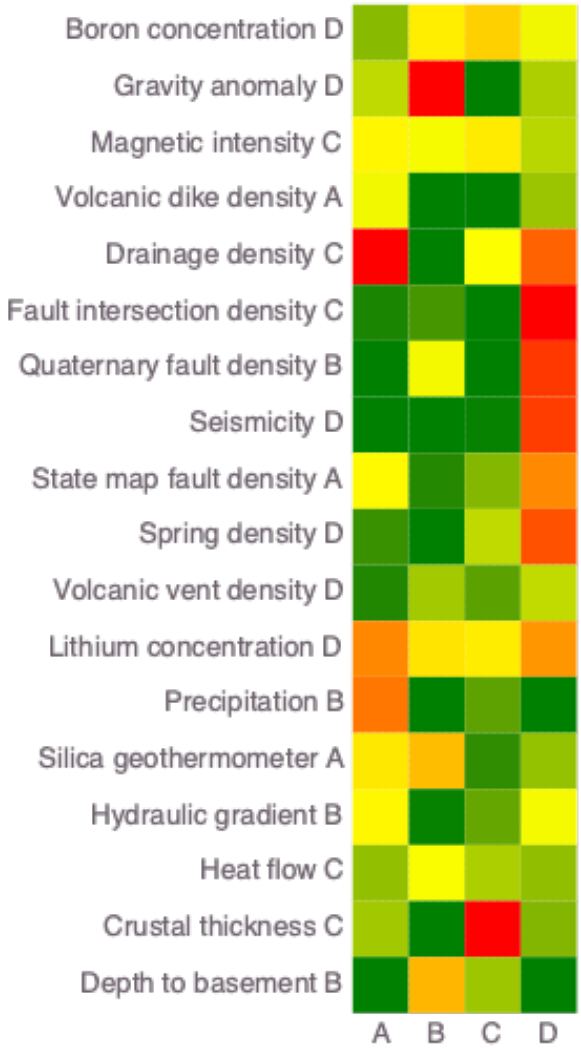

Signal 1
Signal 2
Signal 3
Signal 4
Socorro Can
Ojitos spr
Ojo Canas
T or C spr
B.Iorio well
Laguna Pbl
Warm spr
Allen spr
Jerry well
Aragon spr
Ojo Caliente
Gila spr 2
Well 1
Ojo Canas




```
3×2 Array{Any,2}:
 "Silica geothermometer"    0.565319
 "State map fault density"  0.516354
 "Volcanic dike density"    0.46948

4×2 Array{Any,2}:
 "Depth to basement"         0.698015
 "Quaternary fault density"  0.473285
 "Hydraulic gradient"        0.00393436
 "Precipitation"             0.0

5×2 Array{Any,2}:
 "Crustal thickness"           1.0
```

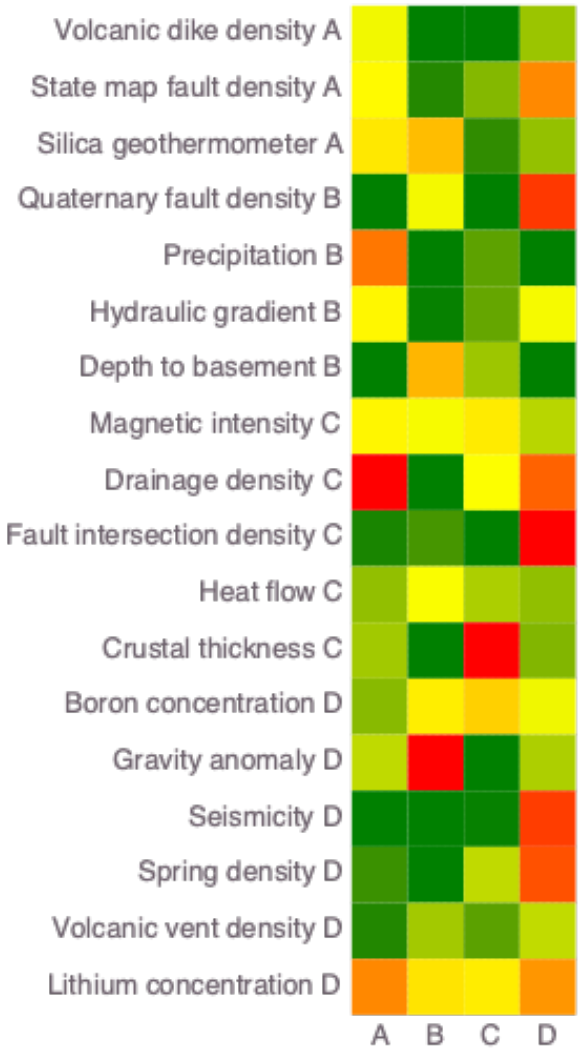
```
 "Magnetic intensity"          0.556994
 "Drainage density"            0.495465
 "Heat flow"                   0.311164
 "Fault intersection density"  0.0
```

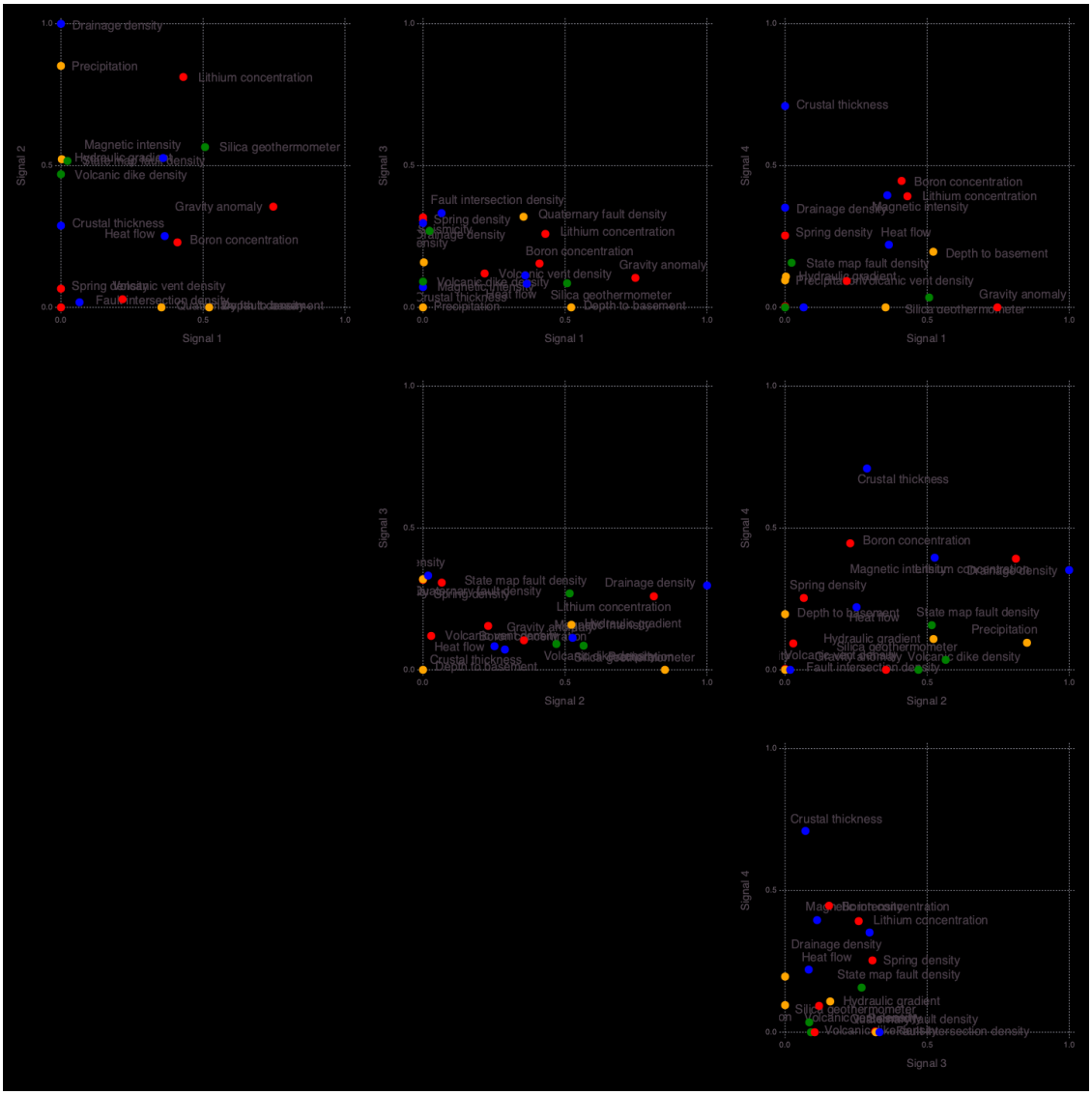
```
6×2 Array{Any,2}:
 "Seismicity"              0.95485
 "Spring density"          0.924999
 "Lithium concentration"   0.779688
 "Boron concentration"     0.465497
 "Volcanic vent density"   0.359763
 "Gravity anomaly"         0.313199
```

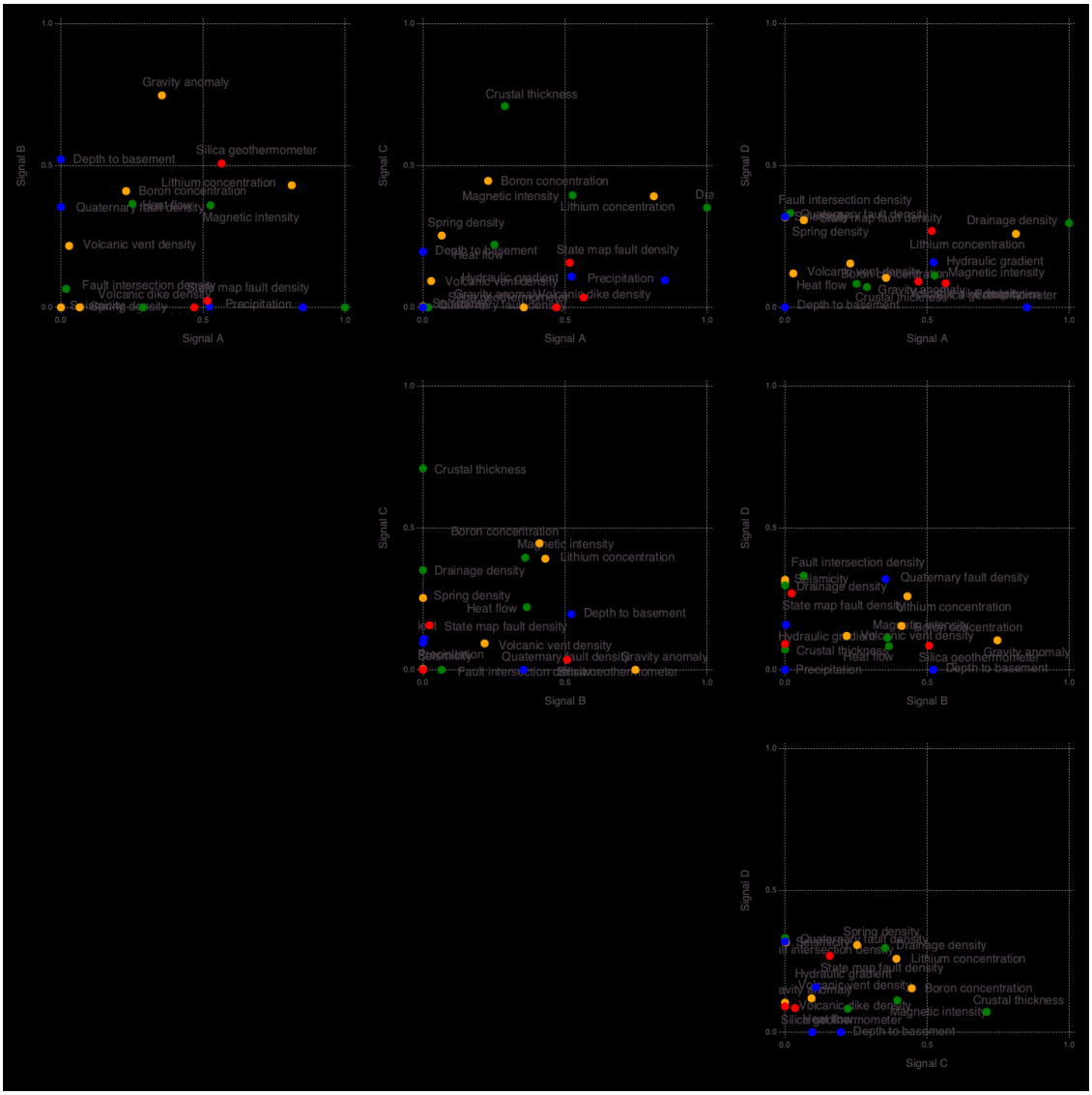


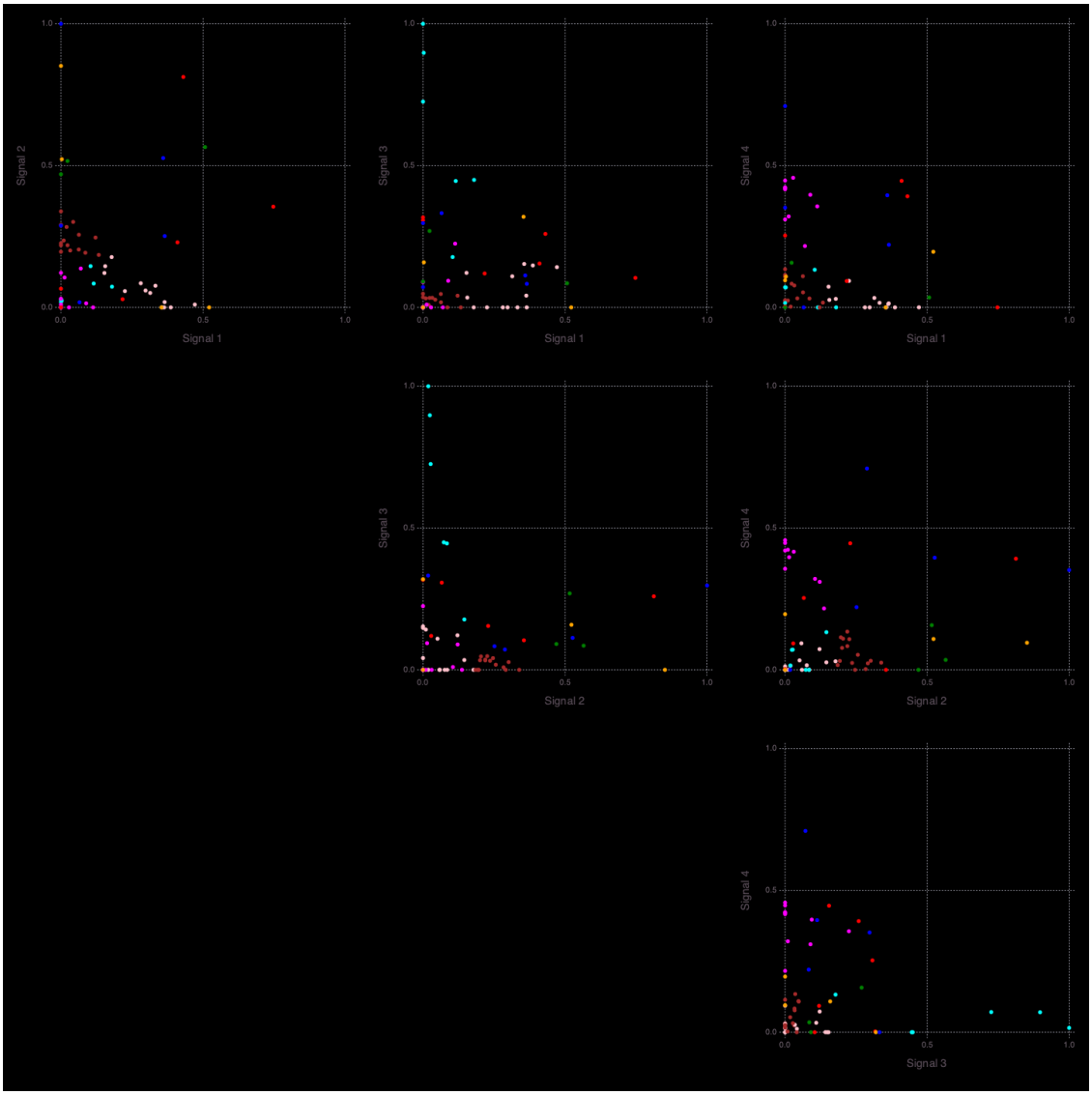

```
 Info: Attributes (signals=4)
```

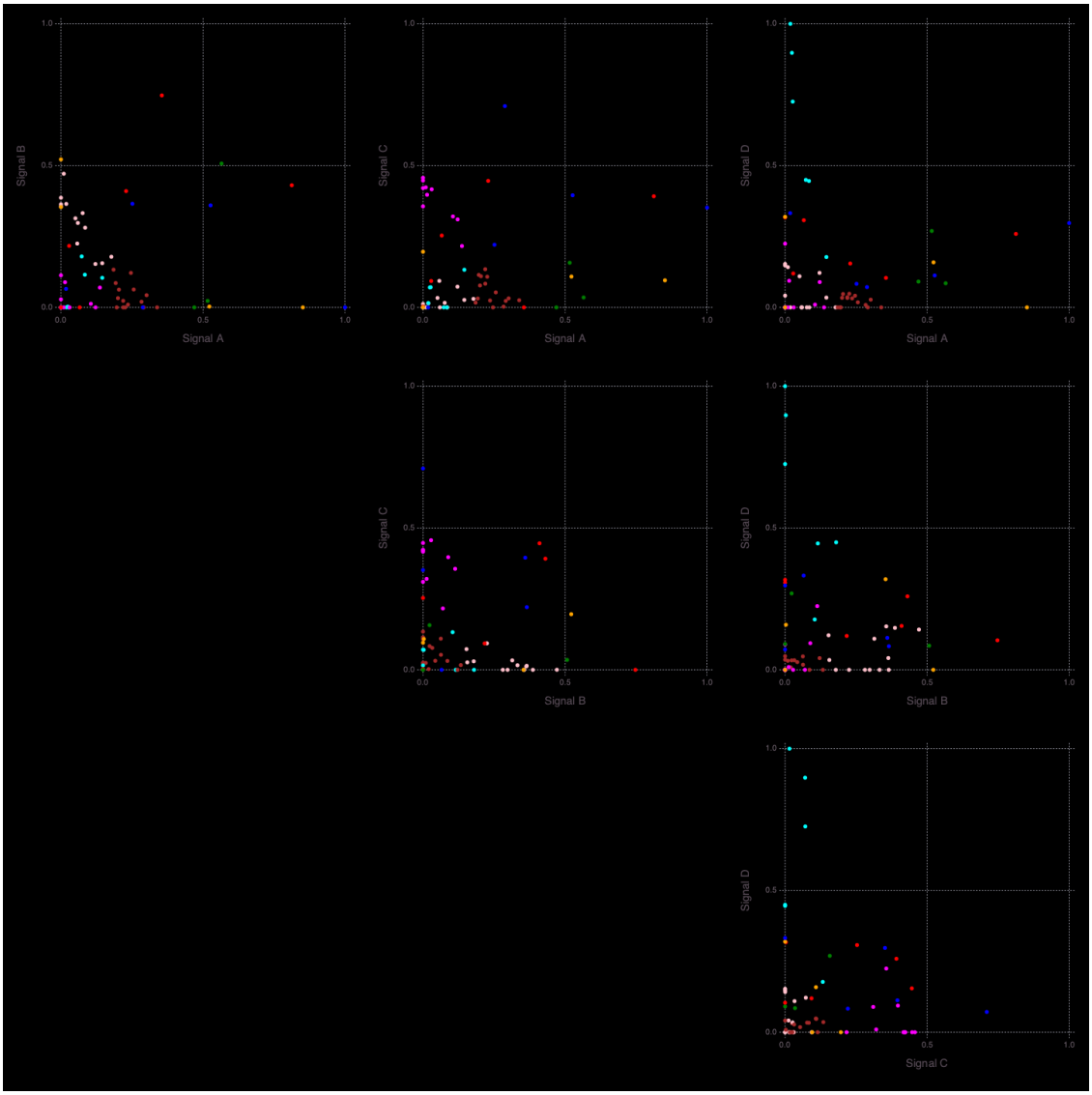
```
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:322
Info: Signal A (S3) Count: 6
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal B (S4) Count: 5
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal C (S1) Count: 4
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal D (S2) Count: 3
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal D -> A Count: 3
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal C -> B Count: 4
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal B -> C Count: 5
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal A -> D Count: 6
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal A (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal B (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal C (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal D (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
```

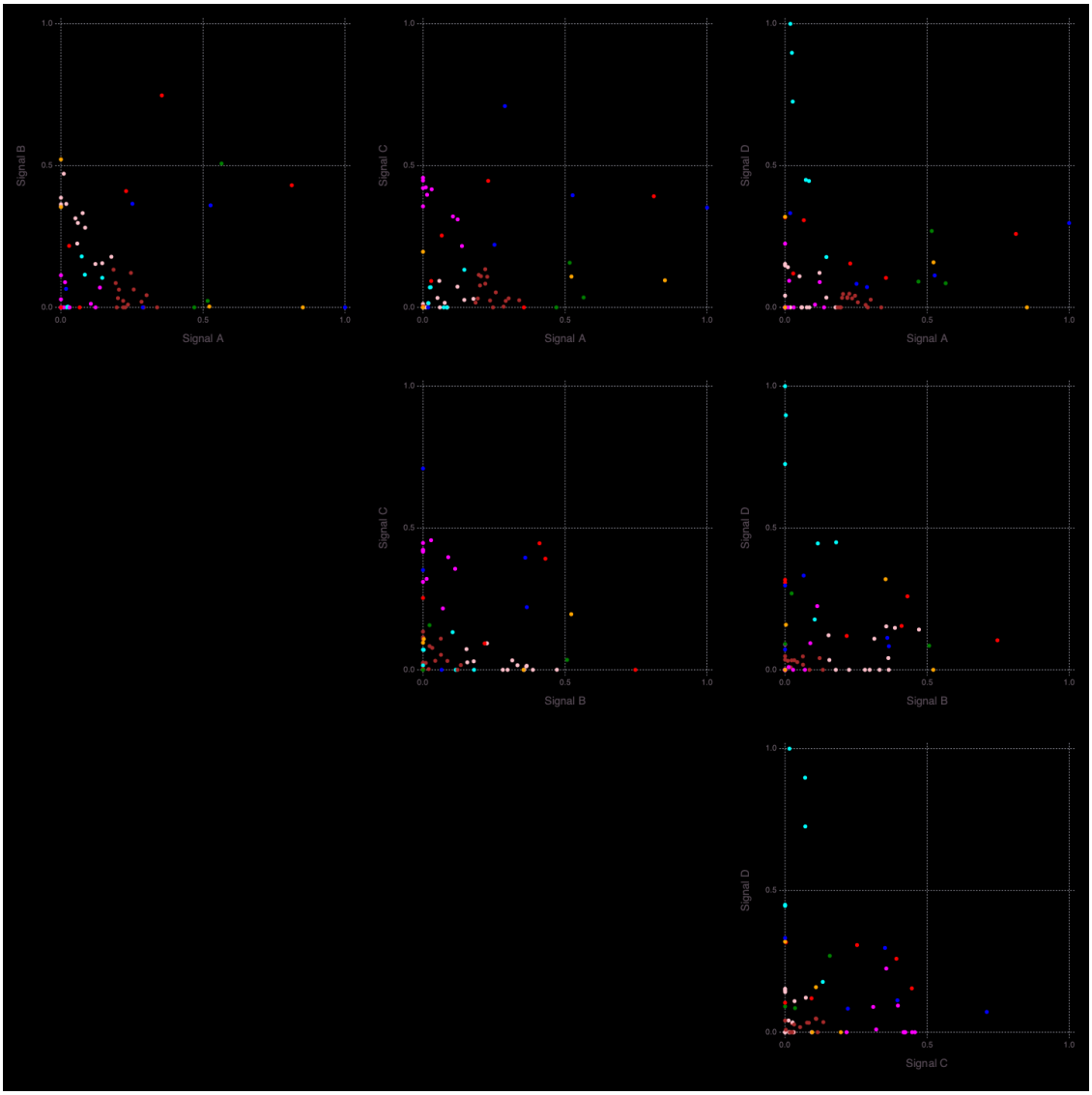

Volcanic dike density A
State map fault density A
Silica geothermometer A
Quaternary fault density B
Precipitation B
Hydraulic gradient B
Depth to basement B
Magnetic intensity C
Drainage density C
Fault intersection density C
Heat flow C
Crustal thickness C
Boron concentration D
Gravity anomaly D
Seismicity D
Spring density D
Volcanic vent density D
Lithium concentration D
A
B
C
D


Drainage density
Precipitation
Lithium concentration
Magnetic intensity
Silica geothermometer
Volcanic dike density
Gravity anomaly
Crustal thickness
Heat flow
Boron concentration
Spring density
Fault intersection density
Signal 1
Signal 2
Fault intersection density
Spring density
Quaternary fault density
Lithium concentration
Boron concentration
Gravity anomaly
Volcanic vent density
Silica geothermometer
Depth to basement
Signal 3
Crustal thickness
Boron concentration
Lithium concentration
Magnetic intensity
Drainage density
Spring density
Heat flow
Depth to basement
State map fault density
Gravity anomaly
Signal 4
State map fault density
Drainage density
Lithium concentration
Gravity anomaly
Heat flow
Crustal thickness
Depth to basement
Boron concentration
Spring density
Precipitation
Silica geothermometer
Volcanic dike density
Fault intersection density


Signal A
Signal B
Signal C
Signal D
Gravity anomaly
Depth to basement
Silica geothermometer
Lithium concentration
Boron concentration
Quaternary fault density
Magnetic intensity
Volcanic vent density
Fault intersection density
State map fault density
Volcanic dike density
Precipitation
Spring density
Crustal thickness
Heat flow
Hydraulic gradient
Drainage density
Seismicity


Signal 2
Signal 1
Signal 3
Signal 1
Signal 4
Signal 1
Signal 3
Signal 2
Signal 4
Signal 2
Signal 4
Signal 3

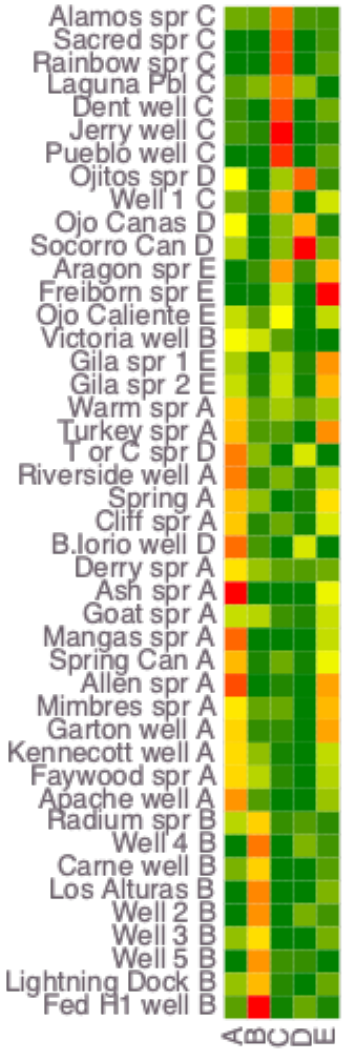

Signal B
Signal A
Signal C
Signal A
Signal D
Signal A
Signal C
Signal B
Signal D
Signal B
Signal D
Signal C




```
Signal importance (high->low): [1, 4, 2, 3, 5]
  Info: Number of signals: 5
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:144
  Info: Locations (signals=5)
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:148
  Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
  @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
  Info: Robust k-means analysis results are loaded from file results-
case01/Hmatrix-5-5_44-1000.jld!
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
  Warning: Procedure to find unique signals could not identify a solution …
```

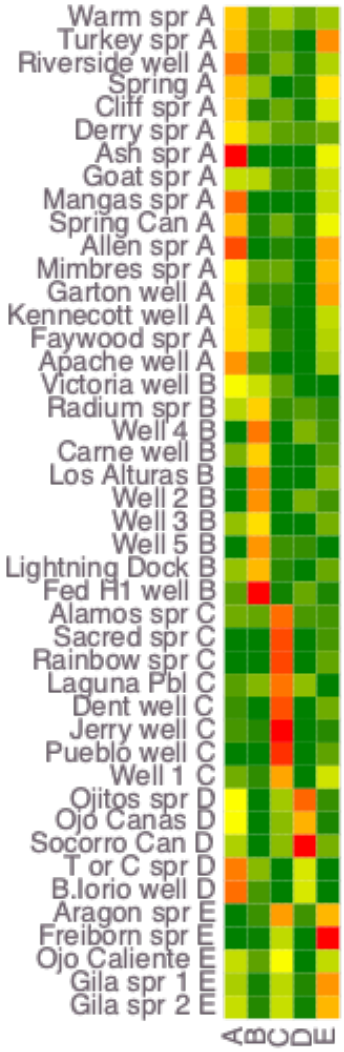
```
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
  @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
  Info: Robust k-means analysis results are loaded from file results-
case01/Wmatrix-5-5_18-1000.jld!
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67

16×2 Array{Any,2}:
 "Ash spr"         1.0
 "Allen spr"       0.932476
 "Mangas spr"      0.883364
 "Riverside well"  0.834285
 "Apache well"     0.782126
 "Spring Can"      0.691235
 "Turkey spr"      0.677725
 "Spring"          0.676908
 "Cliff spr"       0.650192
 "Warm spr"        0.649358
 "Garton well"     0.617193
 "Faywood spr"     0.60702
 "Kennecott well"  0.598779
 "Derry spr"       0.578414
 "Mimbres spr"     0.564978
 "Goat spr"        0.36953

10×2 Array{Any,2}:
 "Fed H1 well"     1.0
 "Well 4"          0.848078
 "Los Alturas"     0.815345
 "Well 2"          0.788889
 "Well 5"          0.777949
 "Lightning Dock"  0.687945
 "Carne well"      0.627357
 "Radium spr"      0.625606
 "Well 3"          0.59283
 "Victoria well"   0.379997

8×2 Array{Any,2}:
 "Jerry well"   1.0
```

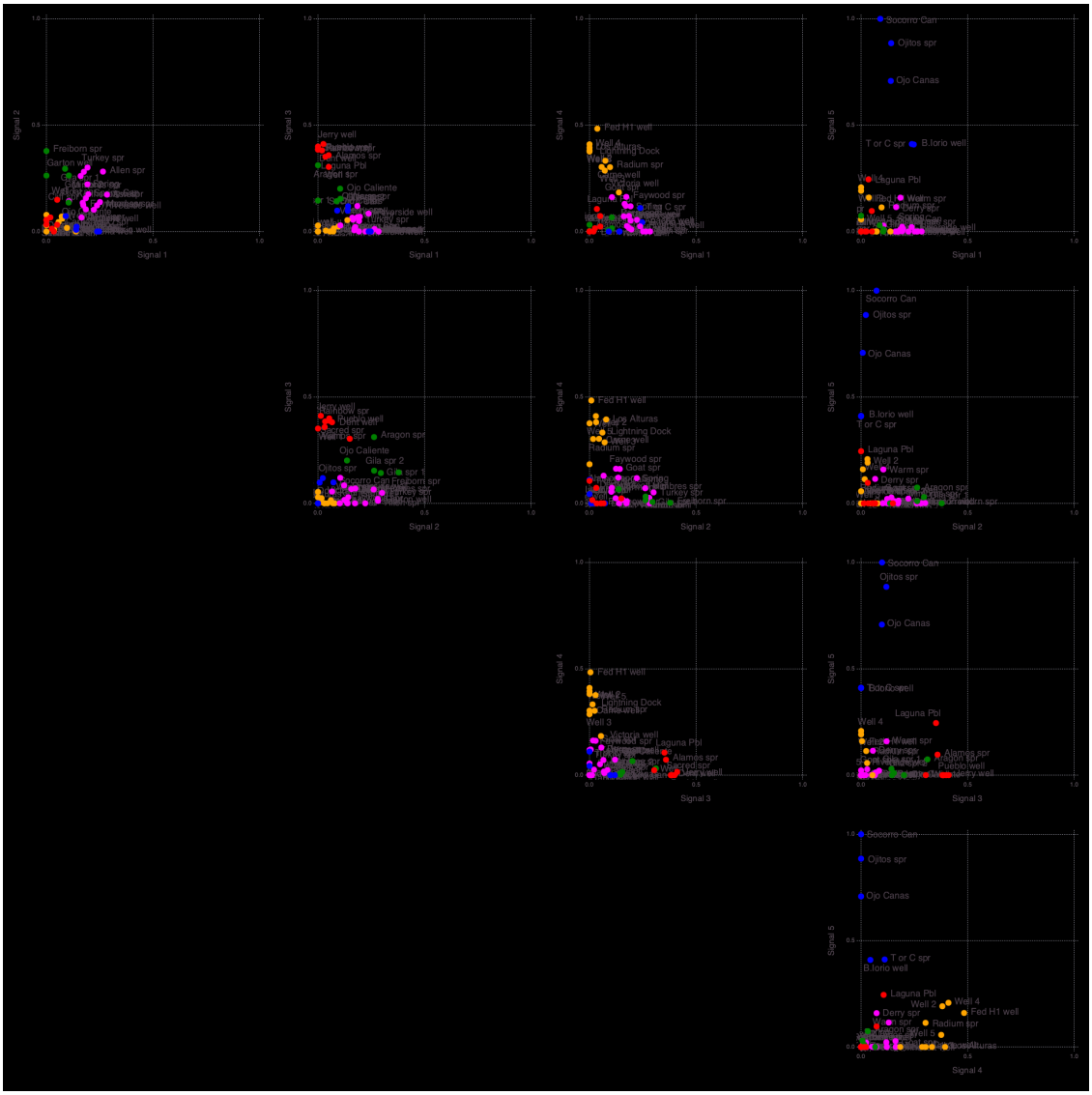
```
 "Pueblo well"  0.971051
 "Rainbow spr"  0.942867
 "Sacred spr"   0.935706
 "Dent well"    0.927135
 "Alamos spr"   0.872535
 "Laguna Pbl"   0.85495
 "Well 1"       0.738413

5×2 Array{Any,2}:
 "Socorro Can"   1.0
 "Ojitos spr"    0.885484
 "Ojo Canas"     0.707981
 "T or C spr"    0.411346
 "B.Iorio well"  0.409252

5×2 Array{Any,2}:
 "Freiborn spr"  1.0
 "Gila spr 1"    0.779561
 "Gila spr 2"    0.695982
 "Aragon spr"    0.695158
 "Ojo Caliente"  0.359767
```

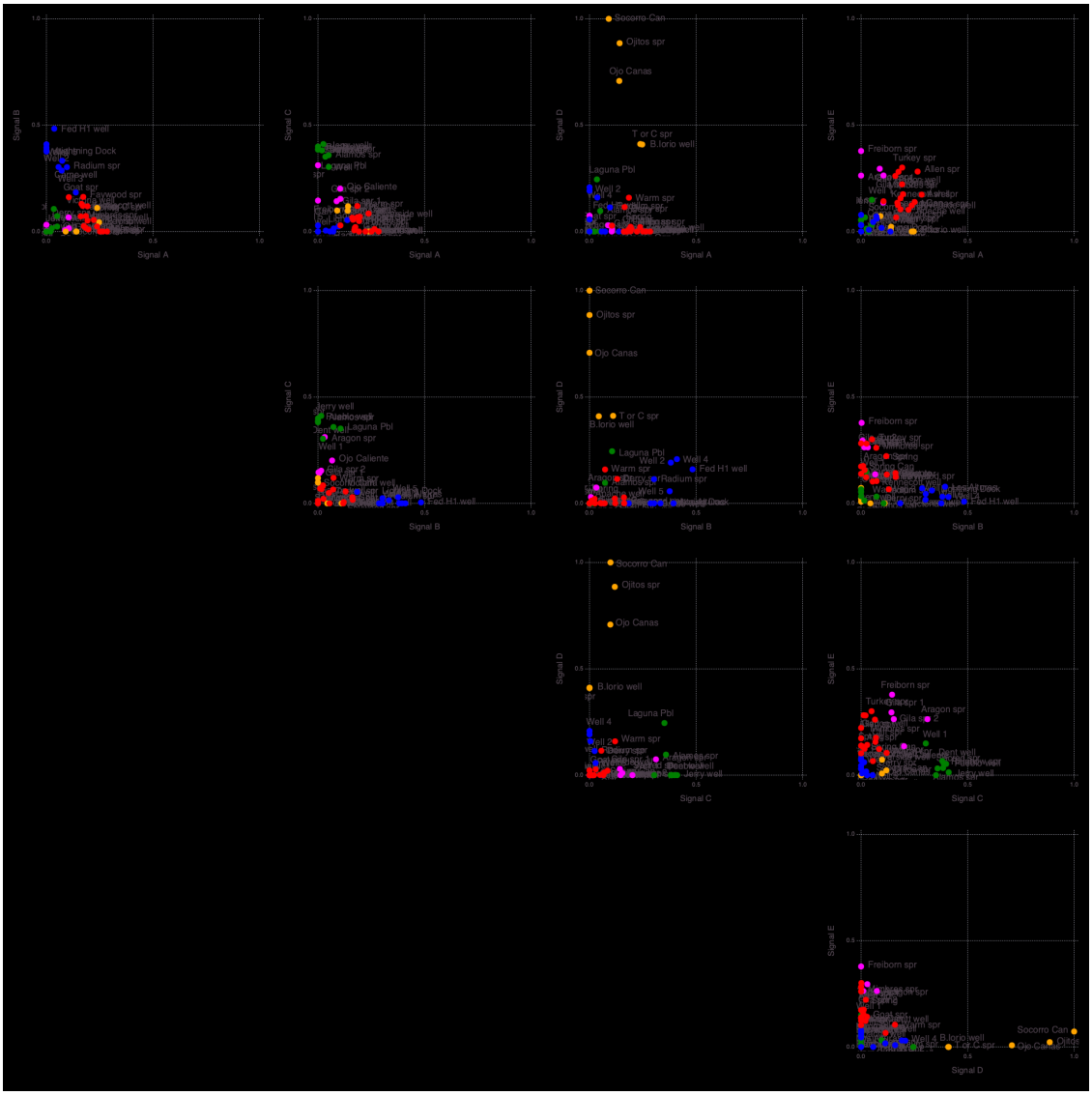


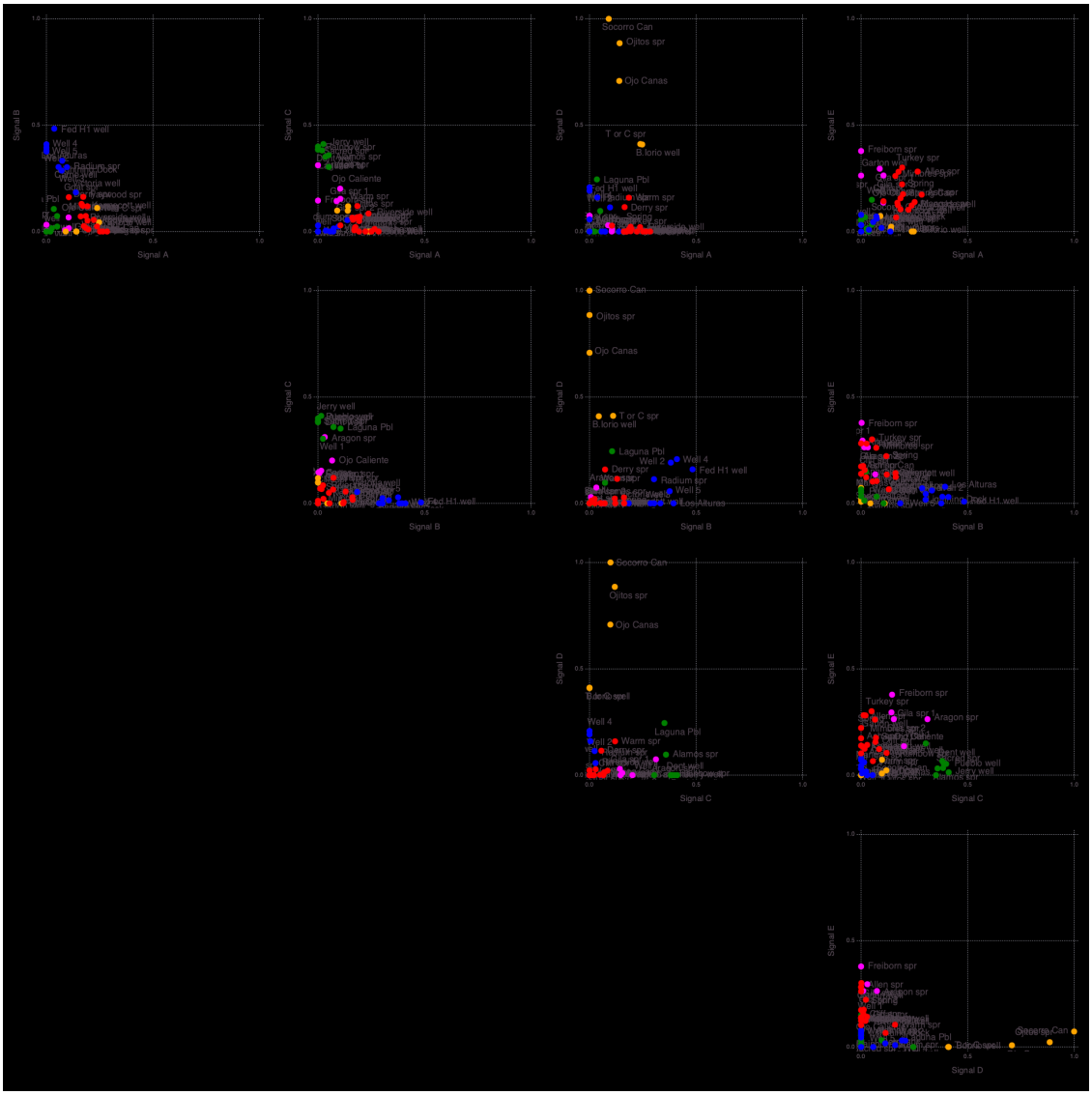

```
Warning: Procedure to find unique signals could not identify a solution …
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
Info: Signal A -> A Count: 16
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
Info: Signal B -> B Count: 10
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
Info: Signal C -> C Count: 8
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
Info: Signal D -> D Count: 5
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
Info: Signal E -> E Count: 5
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
Info: Signal A (S1) (k-means clustering)
```

```
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
Info: Signal B (S4) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
Info: Signal C (S3) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
Info: Signal D (S5) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
Info: Signal E (S2) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
```




Signal 1
Signal 2
Signal 3
Signal 4
Signal 5
Freiborn spr
Turkey spr
Allen spr
Jerry well
Ojo Caliente
Gila spr 2
Ojitos spr
Socorro Can
Ojo Canas
Fed H1 well
Lightning Dock
Radium spr
Faywood spr
B.lorio well
T or C spr
Laguna Pbl
Well 2
Warm spr
Darry spr
Aragon spr
Well 4
Victory well
Alamos spr
Pueblo well


Signal A
Signal B
Signal C
Signal D
Signal E
Fed H1 well
Lightning Dock
Radium spr
Goat spr
Taywood spr
Socorro Can
Ojitos spr
Ojo Canas
T or C spr
B.Iorio well
Laguna Pbl
Well 2
Warm spr
Freiborn spr
Turkey spr
Allen spr
Ojo Caliente
Jerry well
Aragon spr
Well 1
Well 4
Well 5
Aragon spr
Gila spr 2
Dent well

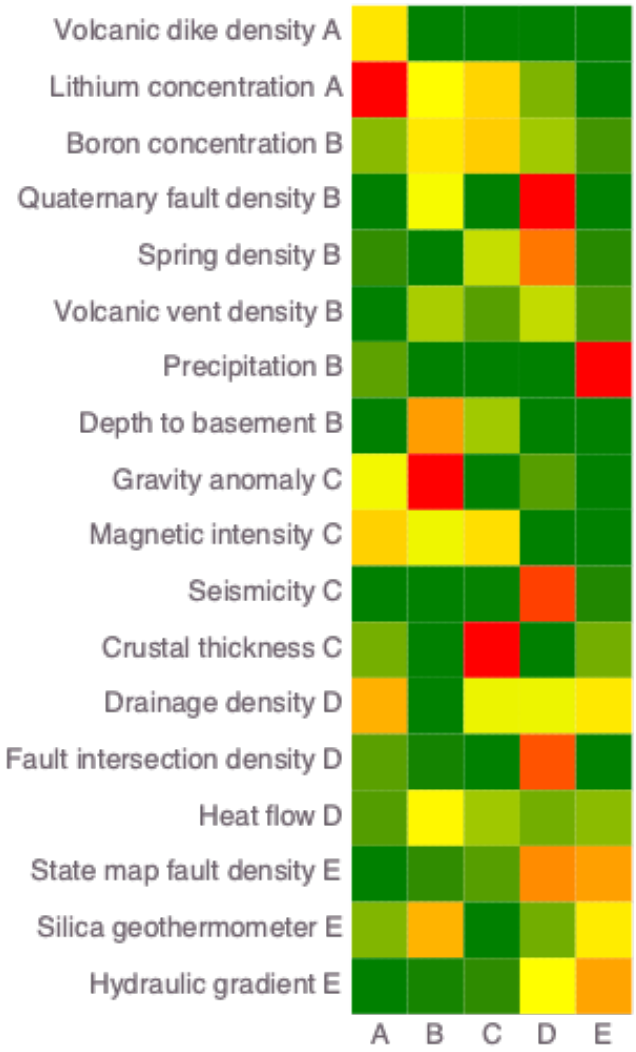


```
2×2 Array{Any,2}:
 "Lithium concentration"  1.0
 "Volcanic dike density"  0.56854
```

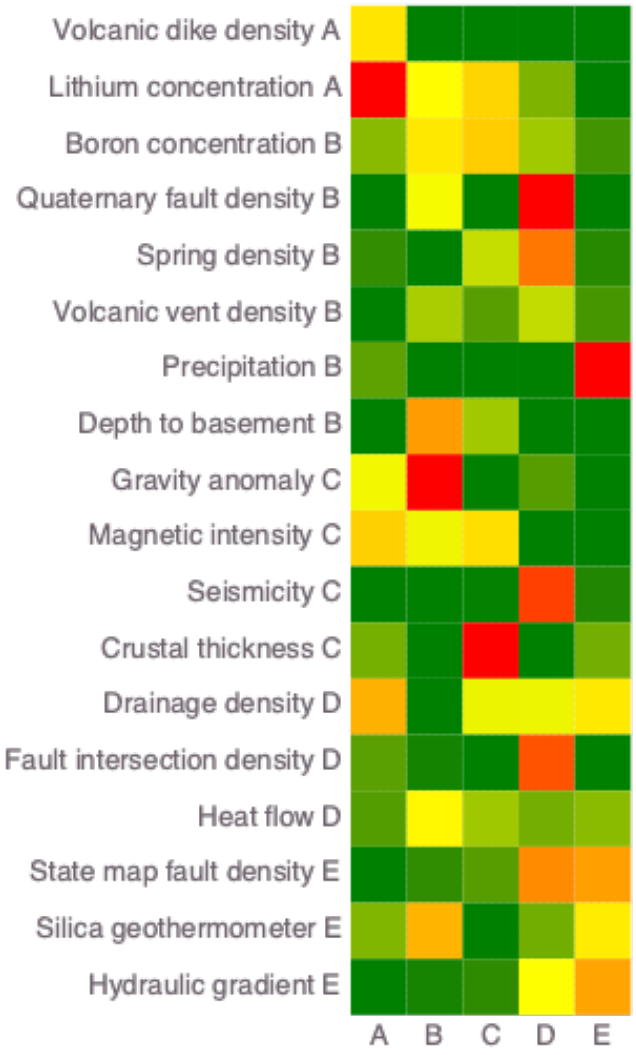
```
6×2 Array{Any,2}:
 "Depth to basement"          0.760709
 "Boron concentration"        0.565134
 "Quaternary fault density"   0.481084
 "Volcanic vent density"      0.303895
 "Spring density"             0.0
 "Precipitation"              0.0
```

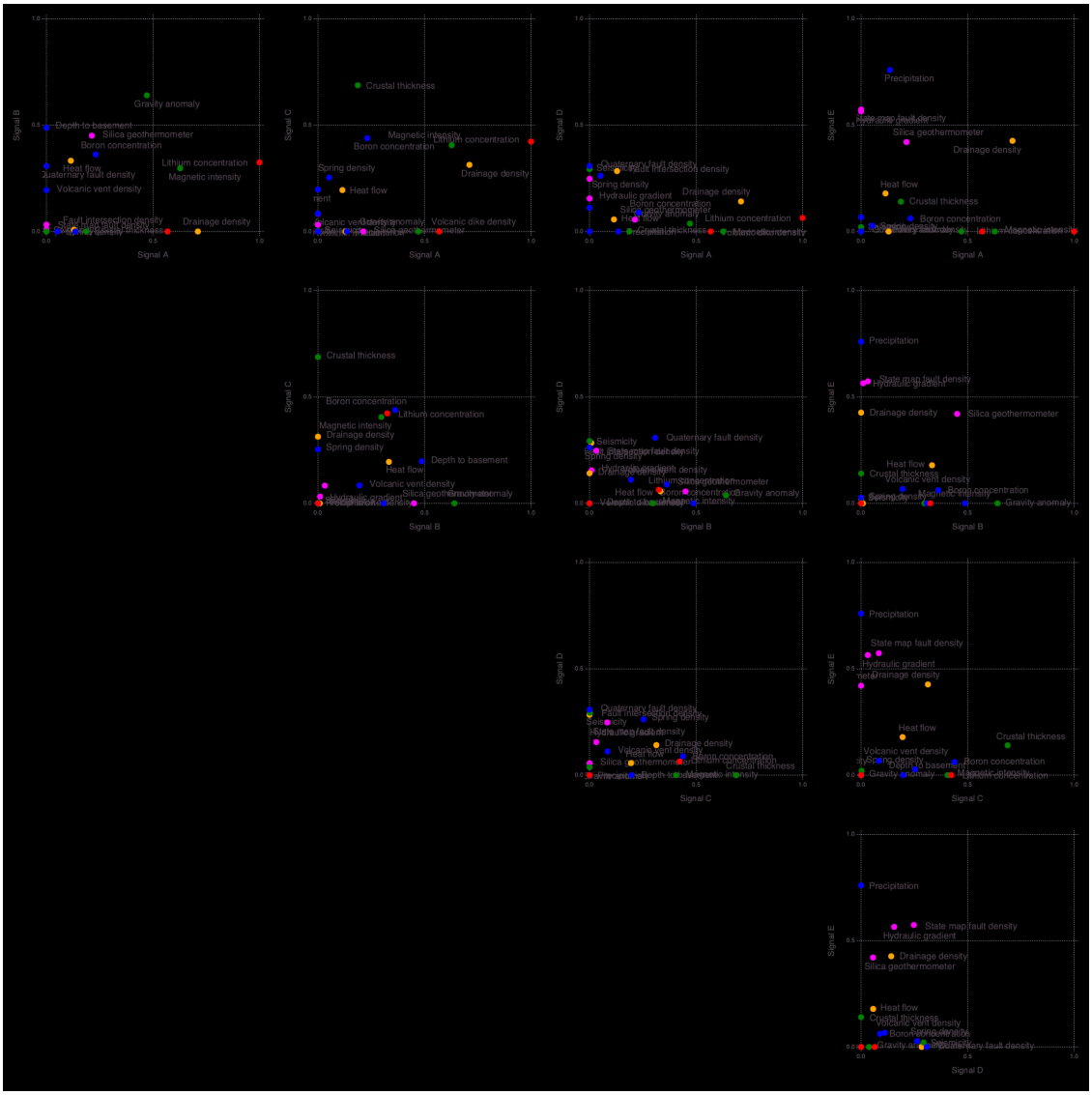
```
4×2 Array{Any,2}:
```

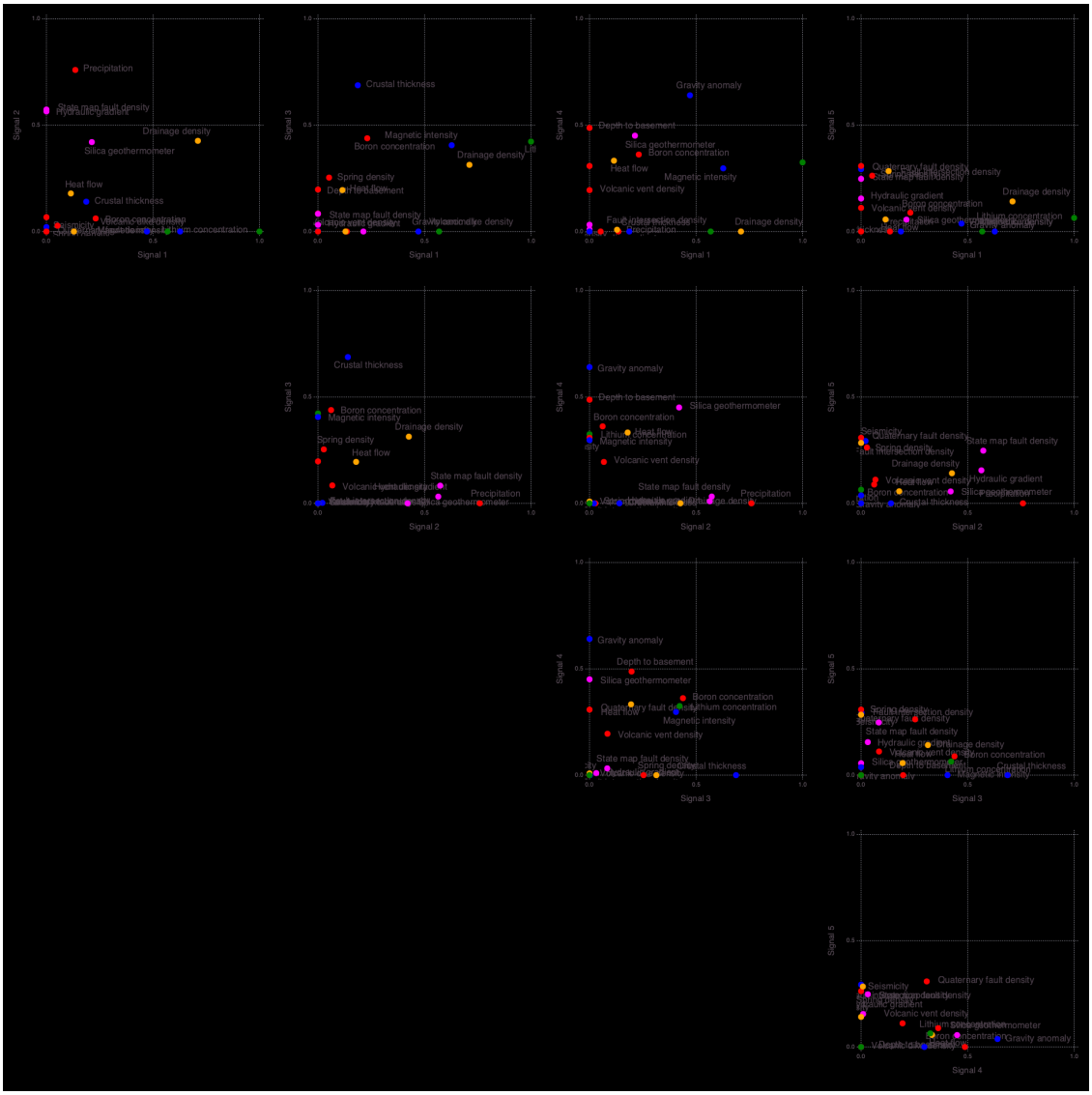
```
 "Crustal thickness"   1.0
 "Magnetic intensity"  0.590051
 "Seismicity"          0.0030882
 "Gravity anomaly"     0.0

3×2 Array{Any,2}:
 "Fault intersection density"  0.921753
 "Drainage density"            0.458627
 "Heat flow"                   0.183895

3×2 Array{Any,2}:
 "State map fault density"  0.755023
 "Hydraulic gradient"       0.743237
 "Silica geothermometer"    0.553526
```

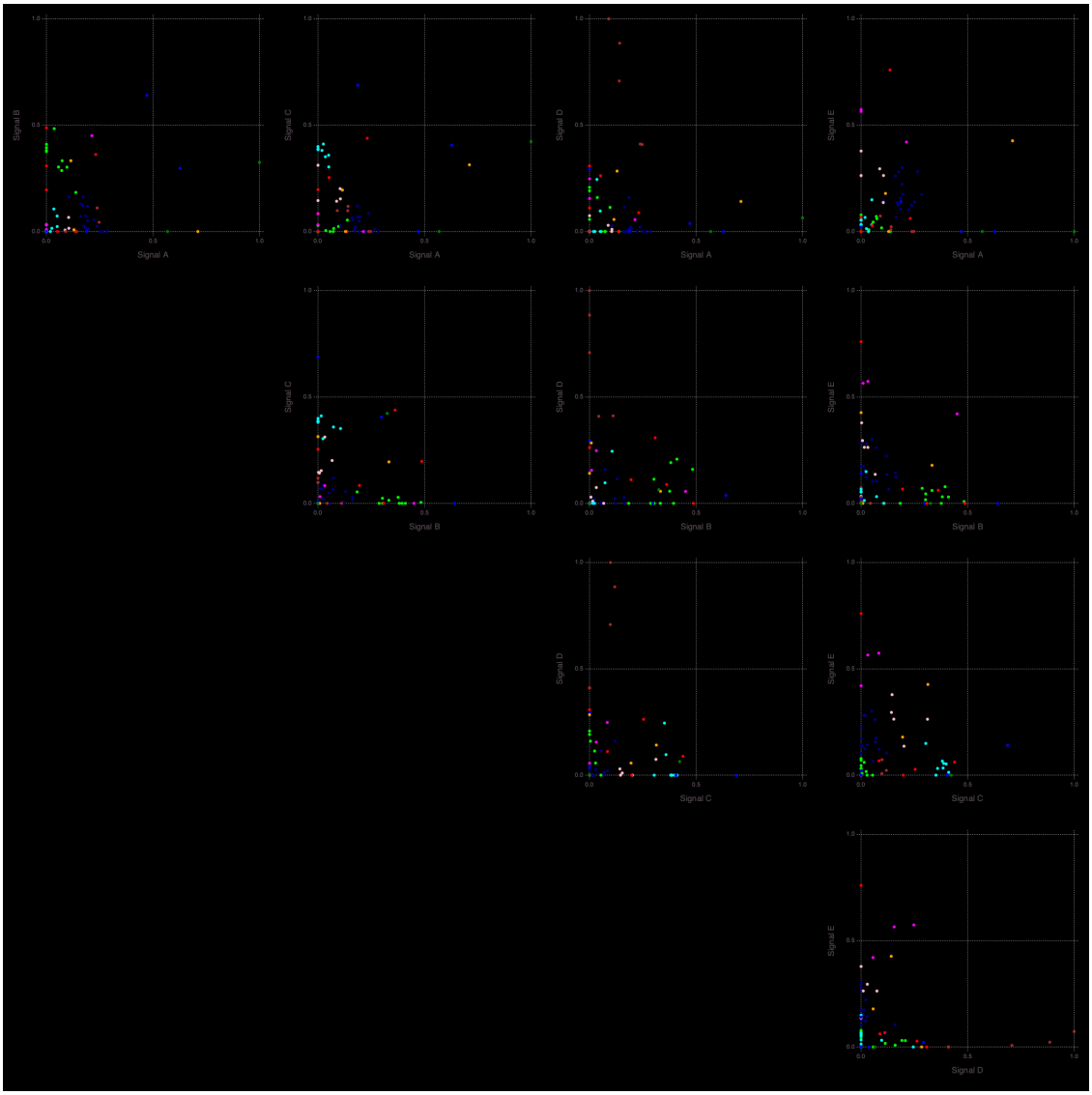


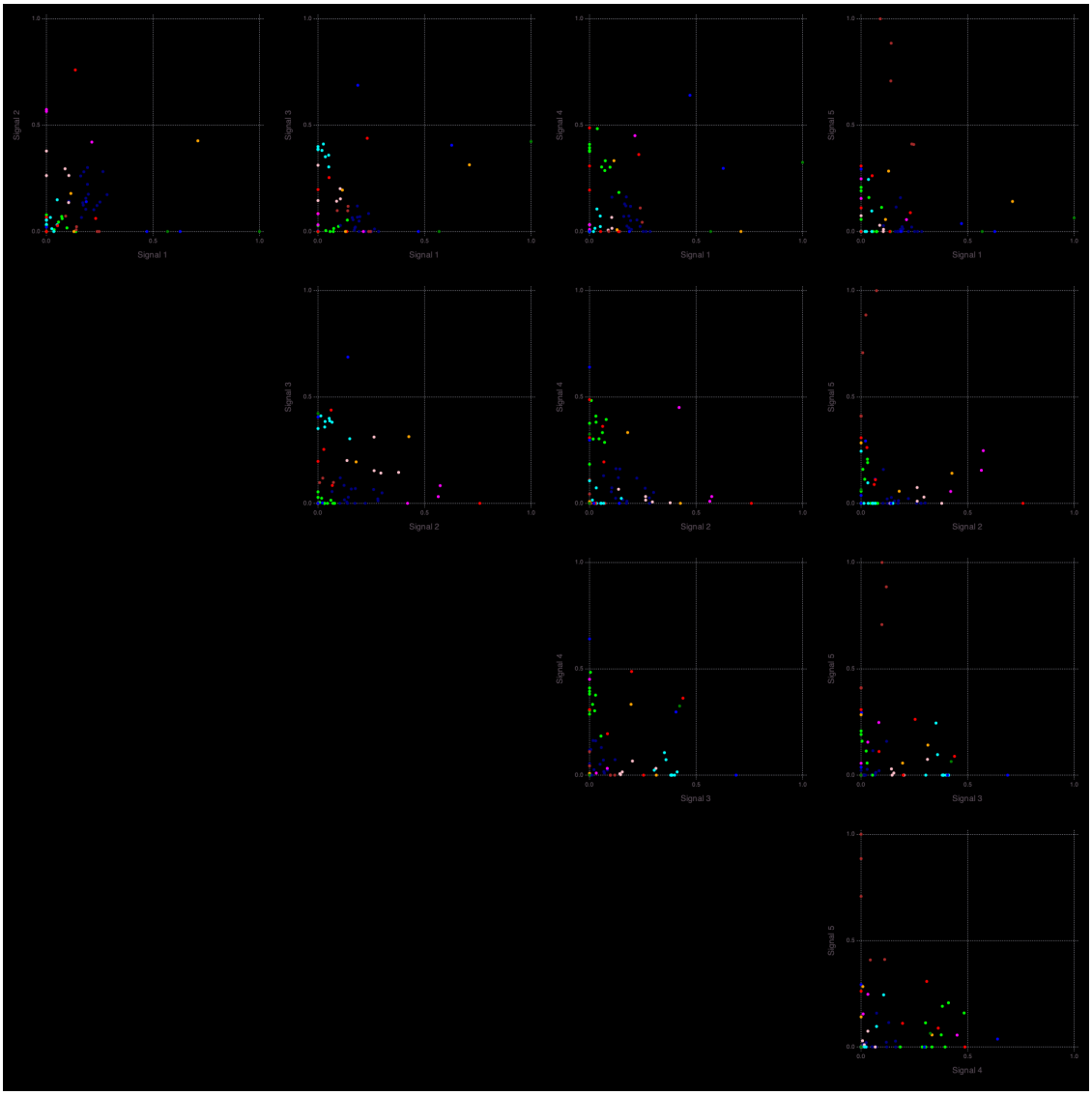
```
Info: Attributes (signals=5)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:322
Info: Signal A (S4) Count: 6
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal B (S3) Count: 4
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal C (S5) Count: 3
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal D (S2) Count: 3
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal E (S1) Count: 2
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal E -> A Count: 2
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal A -> B Count: 6
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal B -> C Count: 4
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal C -> D Count: 3
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal D -> E Count: 3
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal A (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal B (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal C (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal D (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal E (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
```

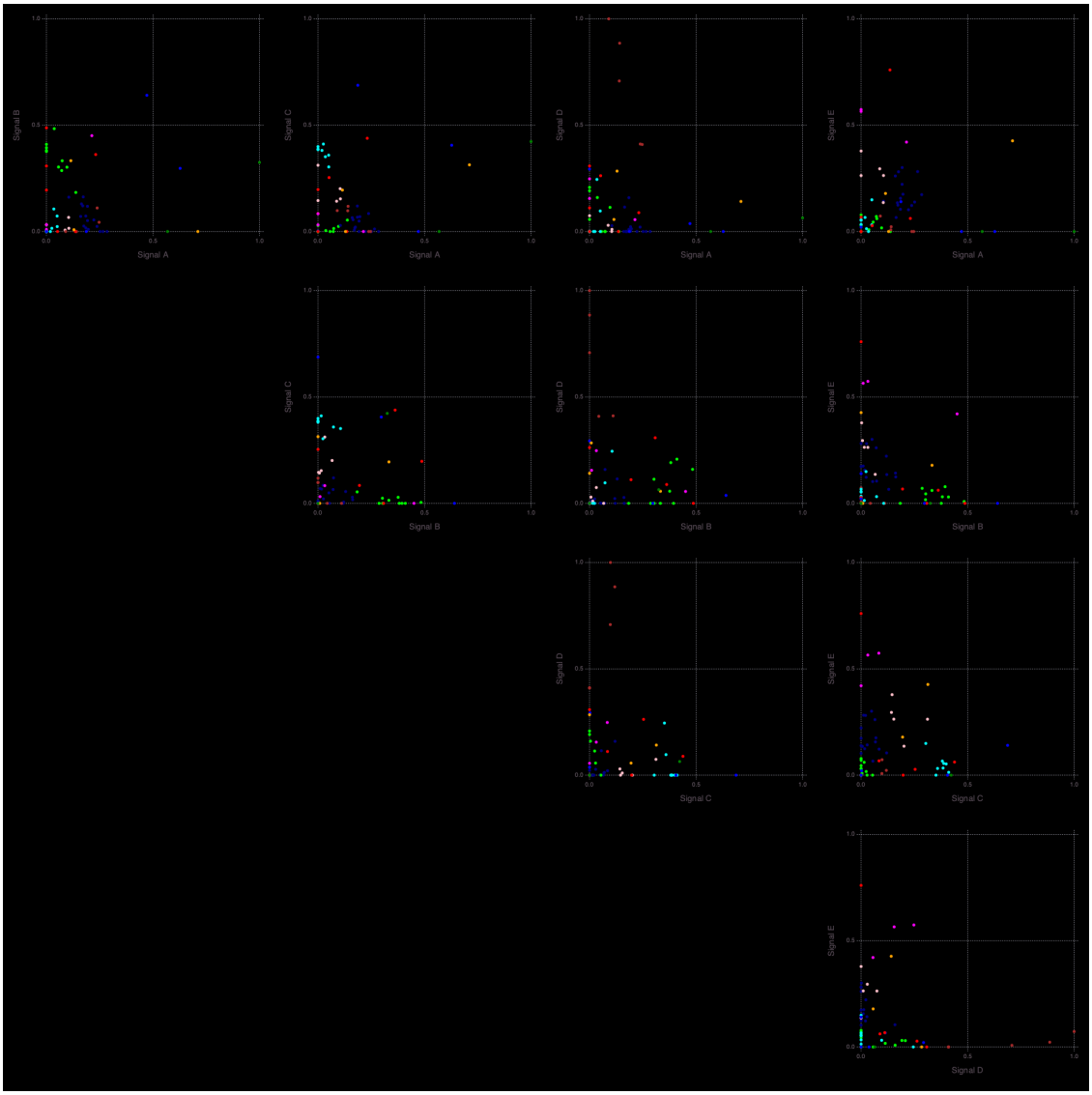

Volcanic dike density A
Lithium concentration A
Boron concentration B
Quaternary fault density B
Spring density B
Volcanic vent density B
Precipitation B
Depth to basement B
Gravity anomaly C
Magnetic intensity C
Seismicity C
Crustal thickness C
Drainage density D
Fault intersection density D
Heat flow D
State map fault density E
Silica geothermometer E
Hydraulic gradient E
A
B
C
D
E


Signal A
Signal B
Signal C
Signal D
Signal E
Gravity anomaly
Depth to basement
Silica geothermometer
Boron concentration
Heat flow
Lithium concentration
Quaternary fault density
Magnetic intensity
Volcanic vent density
Fault intersection density
Drainage density
Crustal thickness
Spring density
Volcanic dike density
Hydraulic gradient
Precipitation
State map fault density
Seismicity


Signal 1
Signal 2
Signal 3
Signal 4
Signal 5
Precipitation
State map fault density
Hydraulic gradient
Drainage density
Silica geothermometer
Heat flow
Crustal thickness
Boron concentration
Magnetic intensity
Spring density
Depth to basement
Gravity anomaly
Volcanic vent density
Quaternary fault density
Seismicity
Lithium concentration


Signal B
Signal A
Signal C
Signal A
Signal D
Signal A
Signal E
Signal A
Signal C
Signal B
Signal D
Signal B
Signal E
Signal B
Signal D
Signal C
Signal E
Signal C
Signal E
Signal D


Signal 2
Signal 1
Signal 3
Signal 1
Signal 4
Signal 1
Signal 5
Signal 1
Signal 3
Signal 2
Signal 4
Signal 2
Signal 5
Signal 2
Signal 4
Signal 3
Signal 5
Signal 3
Signal 5
Signal 4



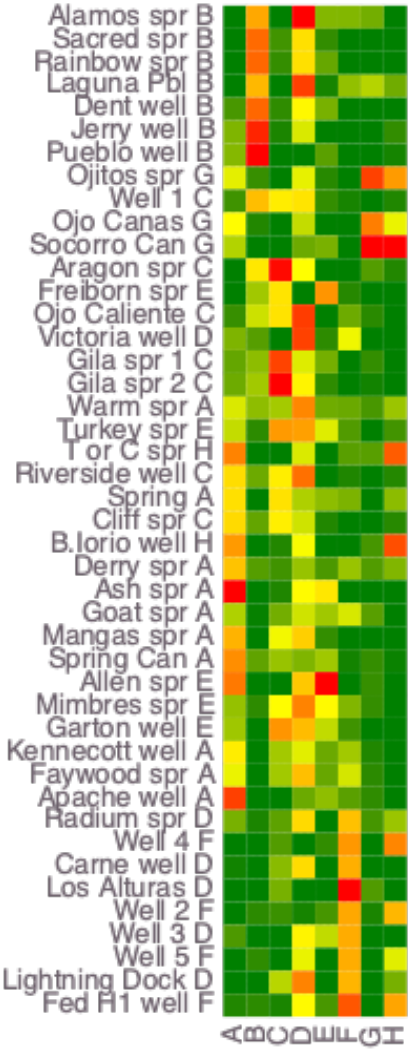

```
Signal importance (high->low): [2, 4, 8, 5, 1, 3, 7, 6]
  Info: Number of signals: 8
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:144
  Info: Locations (signals=8)
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:148
  Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
  @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
```

```
10×2 Array{Any,2}:
 "Ash spr"          1.0
 "Apache well"      0.950743
 "Spring Can"       0.798039
```

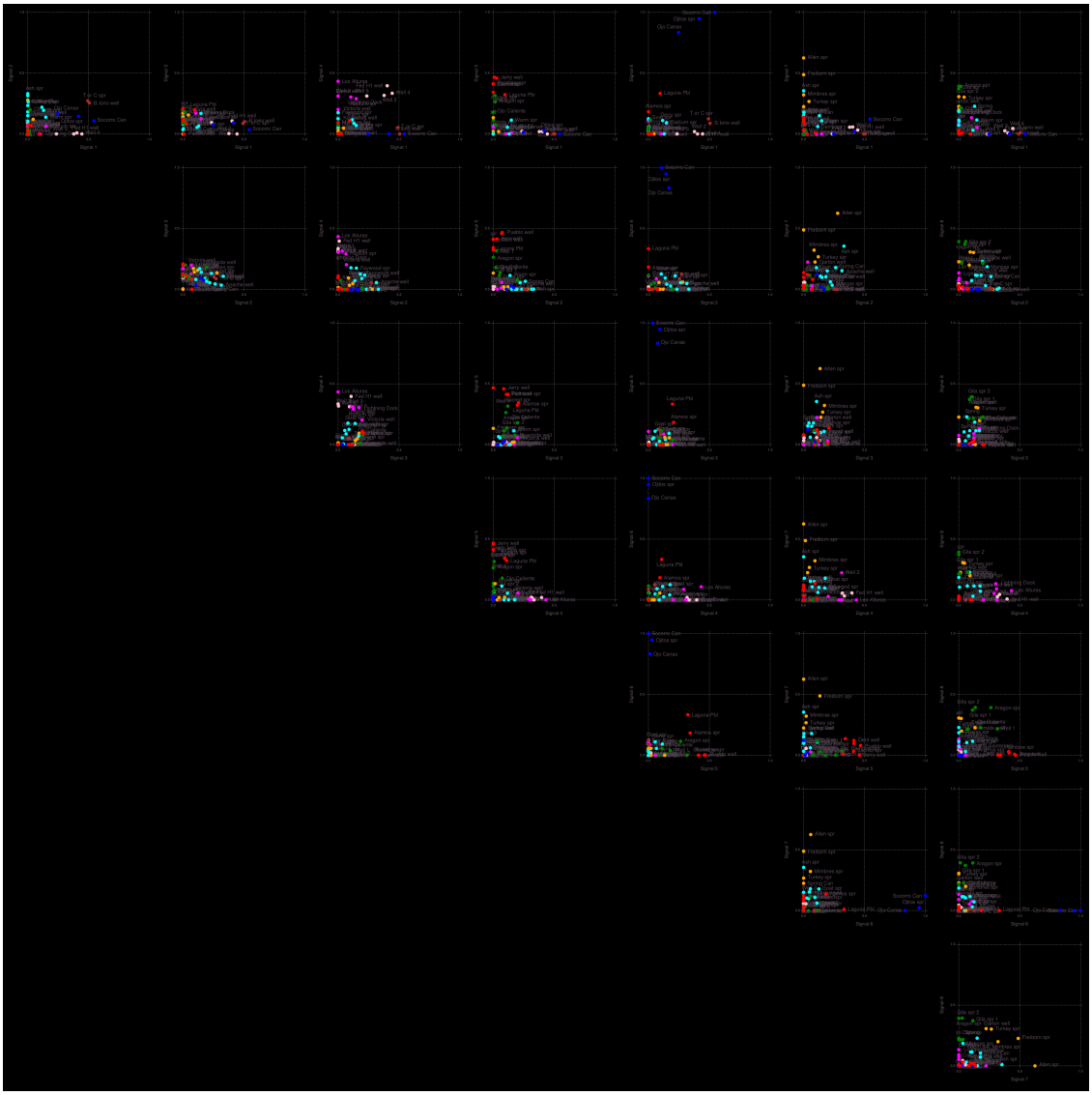
```
 "Mangas spr"      0.70694
 "Derry spr"       0.663338
 "Spring"          0.587286
 "Kennecott well"  0.550769
 "Faywood spr"     0.453699
 "Warm spr"        0.414987
 "Goat spr"        0.31845

7×2 Array{Any,2}:
 "Pueblo well"  1.0
 "Jerry well"   0.982349
 "Dent well"    0.884569
 "Rainbow spr"  0.884056
 "Sacred spr"   0.877946
 "Alamos spr"   0.733233
 "Laguna Pbl"   0.692272

7×2 Array{Any,2}:
 "Gila spr 2"      1.0
 "Aragon spr"      0.997091
 "Gila spr 1"      0.945916
 "Ojo Caliente"    0.578686
 "Well 1"          0.550929
 "Riverside well"  0.549312
 "Cliff spr"       0.5445

6×2 Array{Any,2}:
 "Victoria well"   0.949464
 "Lightning Dock"  0.823669
 "Radium spr"      0.601781
 "Carne well"      0.596224
 "Well 3"          0.531882
 "Los Alturas"     0.0

5×2 Array{Any,2}:
 "Allen spr"     1.0
 "Freiborn spr"  0.780095
 "Mimbres spr"   0.514682
 "Turkey spr"    0.427395
 "Garton well"   0.358771

4×2 Array{Any,2}:
 "Fed H1 well"  0.915735
 "Well 4"       0.772875
 "Well 2"       0.732798
 "Well 5"       0.720996

  Info: Robust k-means analysis results are loaded from file results-
case01/Hmatrix-8-8_44-1000.jld!
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
  Warning: Procedure to find unique signals could not identify a solution …
```

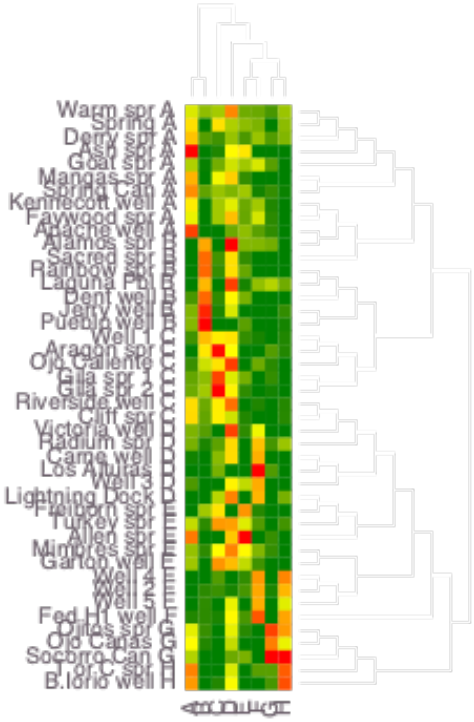
```
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
  @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
  Info: Robust k-means analysis results are loaded from file results-
case01/Wmatrix-8-8_18-1000.jld!
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Info: Signal A -> A Count: 10
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
  Info: Signal B -> B Count: 7
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
  Info: Signal C -> C Count: 7
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
  Info: Signal D -> D Count: 6
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
  Info: Signal E -> E Count: 5
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
  Info: Signal F -> F Count: 4
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
  Info: Signal G -> G Count: 3
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
  Info: Signal H -> H Count: 2
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
  Info: Signal A (S2) (k-means clustering)
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
  Info: Signal B (S5) (k-means clustering)
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
  Info: Signal C (S8) (k-means clustering)
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
  Info: Signal D (S3) (k-means clustering)
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
  Info: Signal E (S7) (k-means clustering)
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
  Info: Signal F (S4) (k-means clustering)
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
```

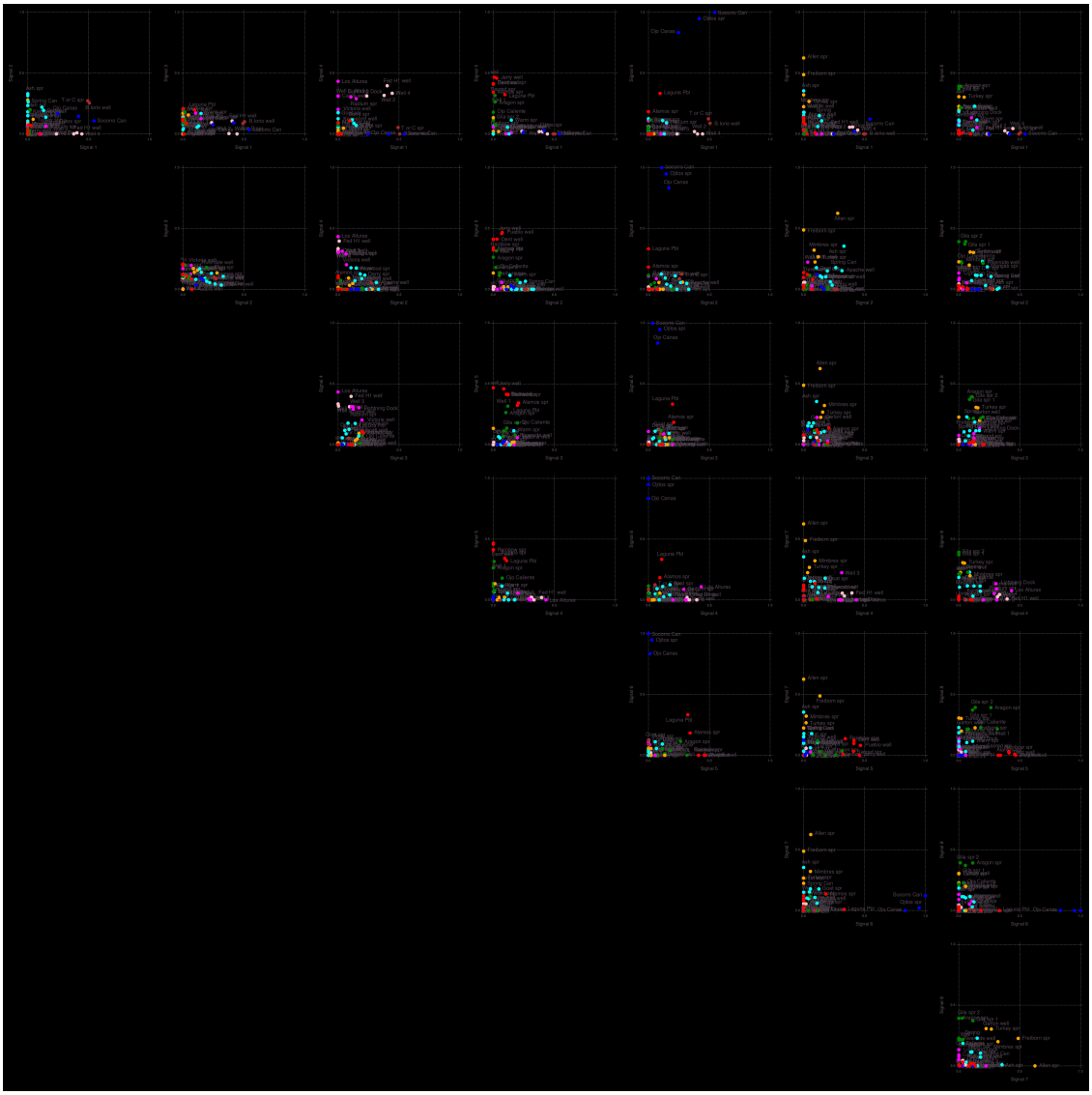
```
3×2 Array{Any,2}:
 "Socorro Can"  1.0
 "Ojitos spr"   0.948793
 "Ojo Canas"    0.834717

2×2 Array{Any,2}:
 "B.Iorio well"  0.929309
 "T or C spr"    0.905042
```

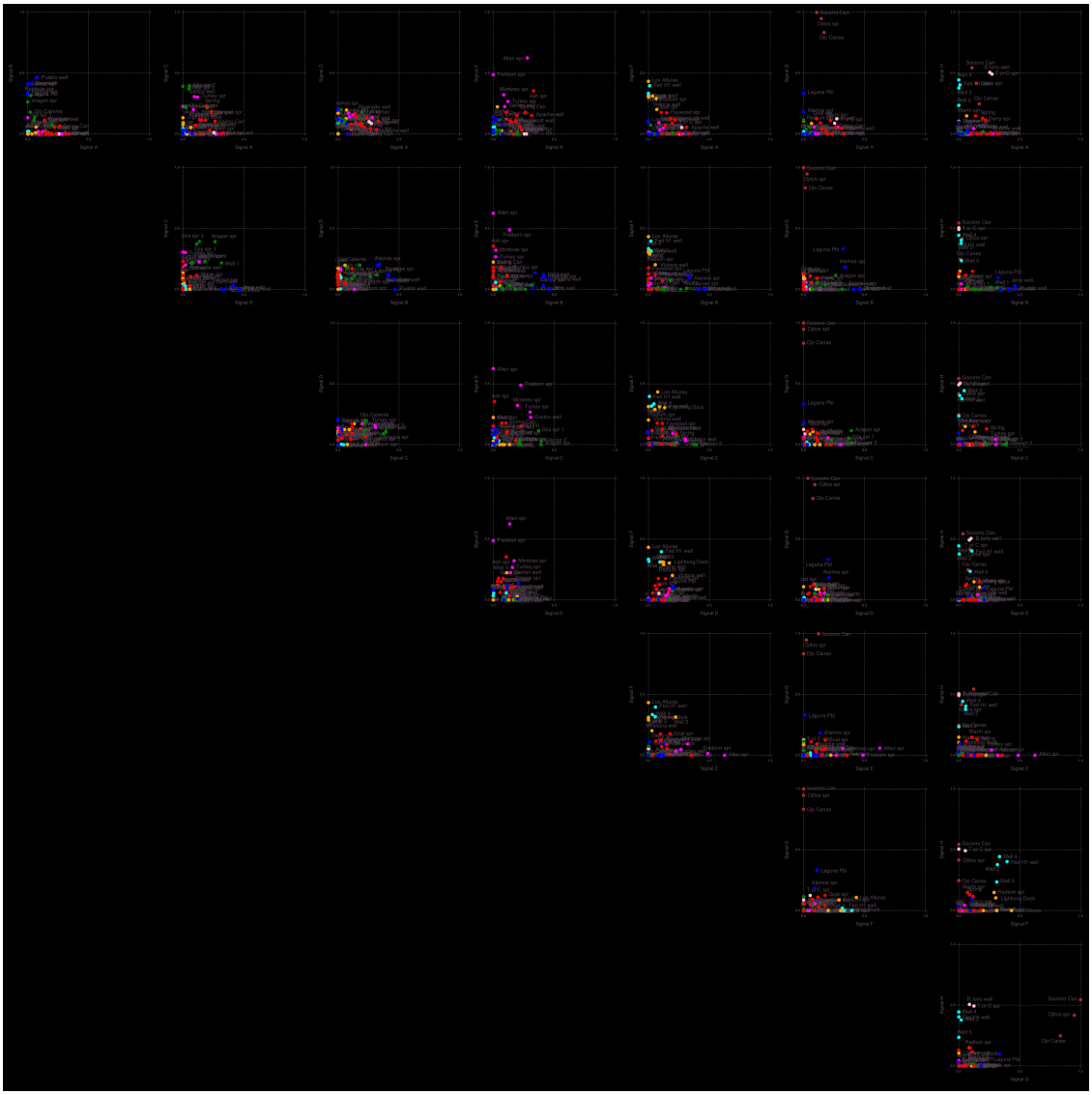



```
 Info: Signal G (S6) (k-means clustering)
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
 Info: Signal H (S1) (k-means clustering)
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
```



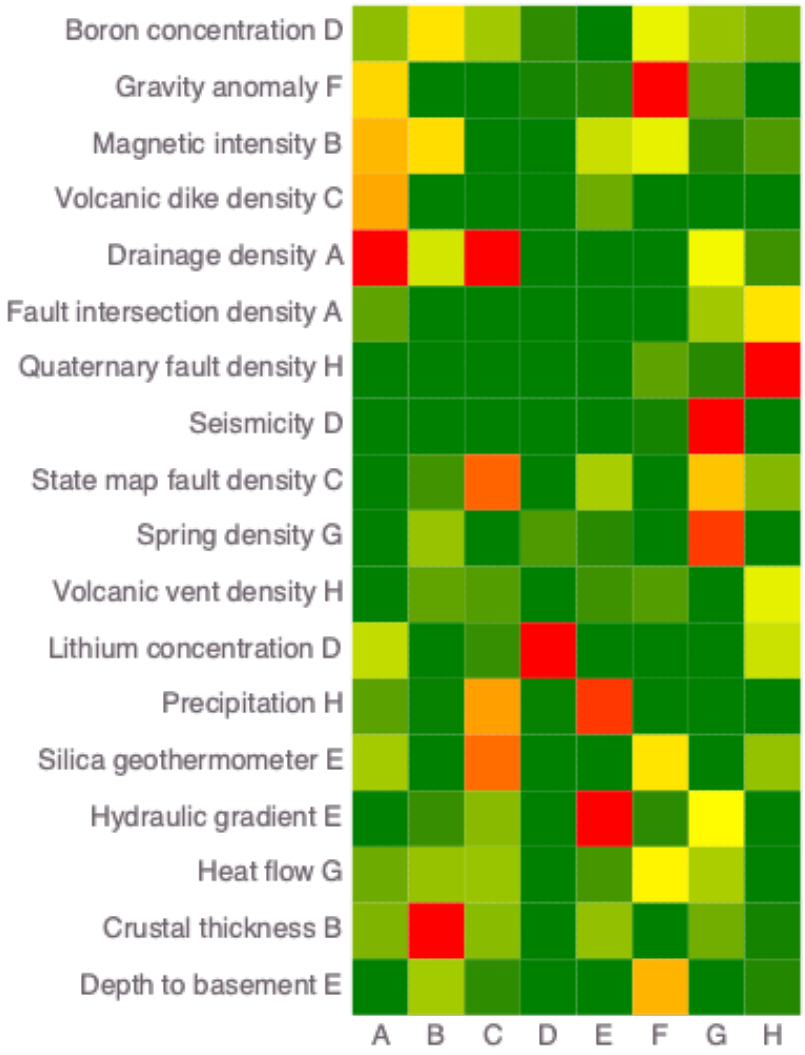

Warm spr A
Spring
Derry spr A
Ash spr A
Goat spr A
Mangas spr A
Spring Can A
Kennecott well A
Faywood spr A
Apache well A
Alamos spr B
Sacred spr B
Rainbow spr B
Laguna Pbl B
Dent well B
Derry well B
Pueblo well B
Well 1
Aragon spr C
Ojo Caliente C
Gila spr 1 C
Gila spr 2 C
Riverside well C
Cliff spr C
Victoria well D
Radium spr D
Came well D
Los Alutas D
Well 3 D
Lightning Dock D
Faulborn spr E
Turkey spr E
Allen spr E
Mimbres spr E
Ganado well E
Well 4 E
Well 2 E
Well 5 E
Fed Ht well E
Ortiz spr G
Old Canas G
Socorro Can G
Ft Craig well H
B.Idrio well H





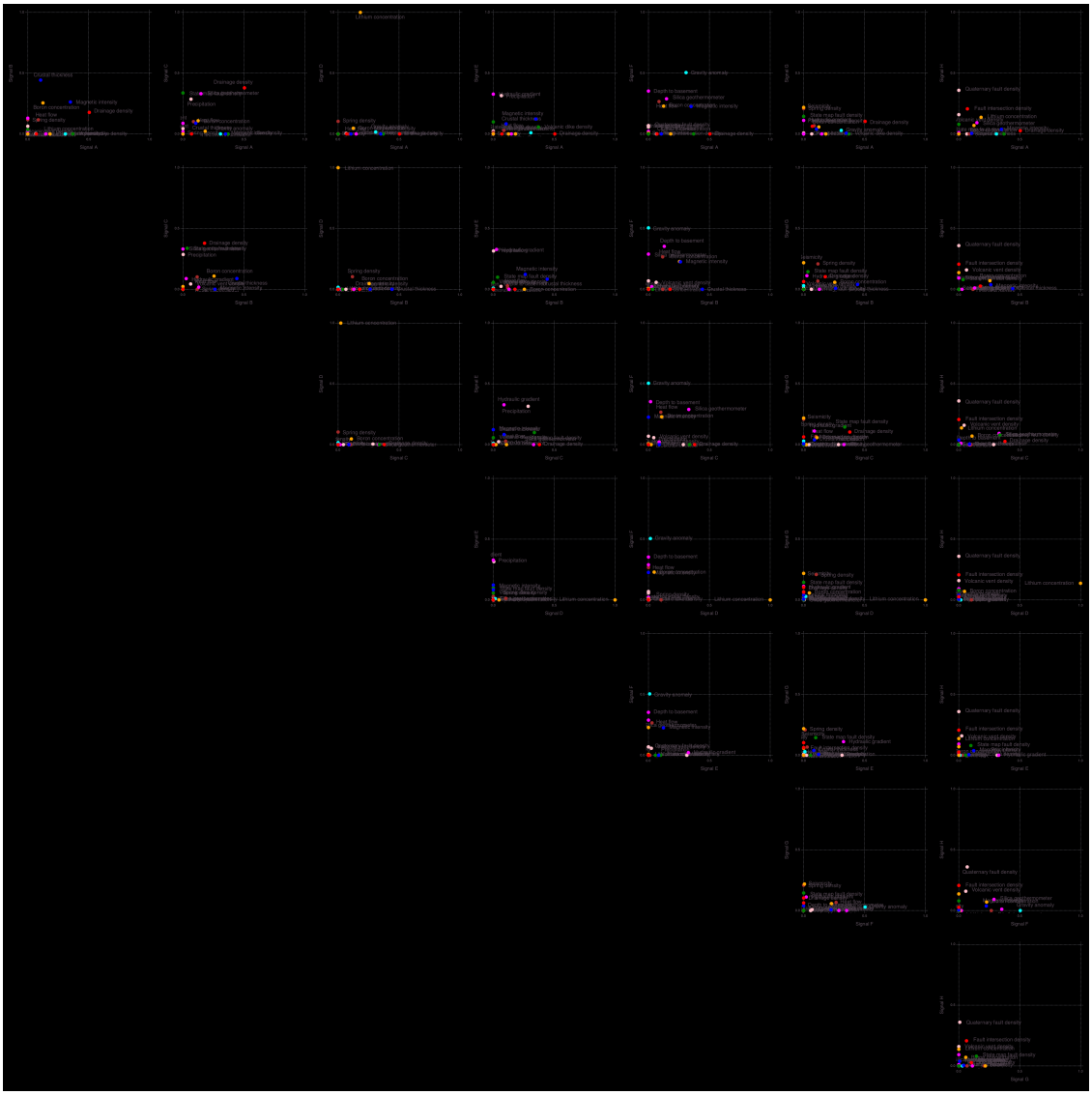
```
2×2 Array{Any,2}:
 "Drainage density"            1.0
 "Fault intersection density"  0.139857

2×2 Array{Any,2}:
 "Crustal thickness"   1.0
 "Magnetic intensity"  0.593375

2×2 Array{Any,2}:
 "State map fault density"  0.889845
 "Volcanic dike density"    0.0

3×2 Array{Any,2}:
```

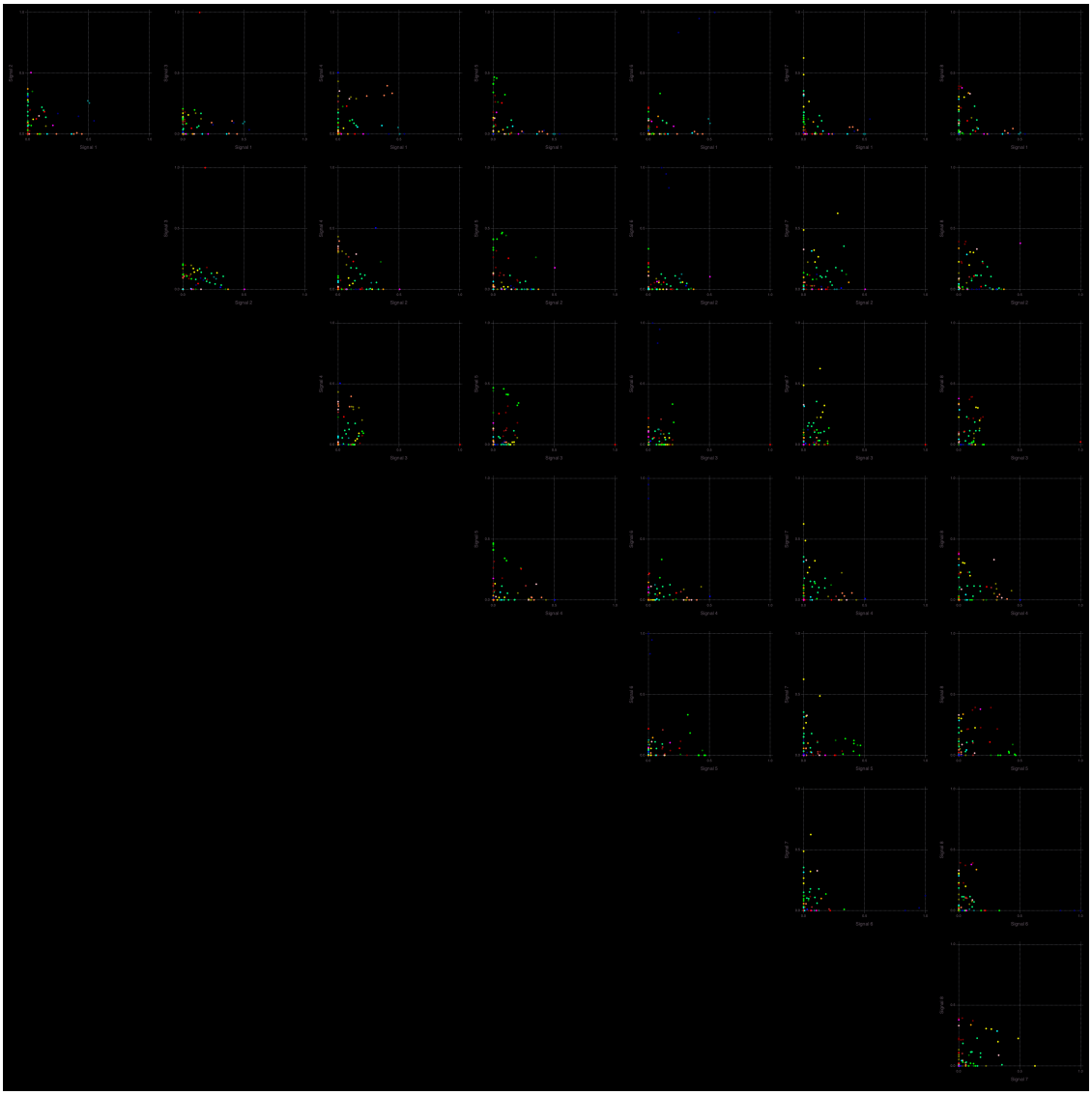
```
 "Lithium concentration"  1.0
 "Boron concentration"    0.0468254
 "Seismicity"             0.0

3×2 Array{Any,2}:
 "Hydraulic gradient"     1.0
 "Silica geothermometer"  0.0
 "Depth to basement"      0.0

1×2 Array{Any,2}:
 "Gravity anomaly"  1.0

2×2 Array{Any,2}:
 "Spring density"  0.957
 "Heat flow"       0.308393

3×2 Array{Any,2}:
 "Quaternary fault density"  1.0
 "Volcanic vent density"     0.442817
 "Precipitation"             0.0
```

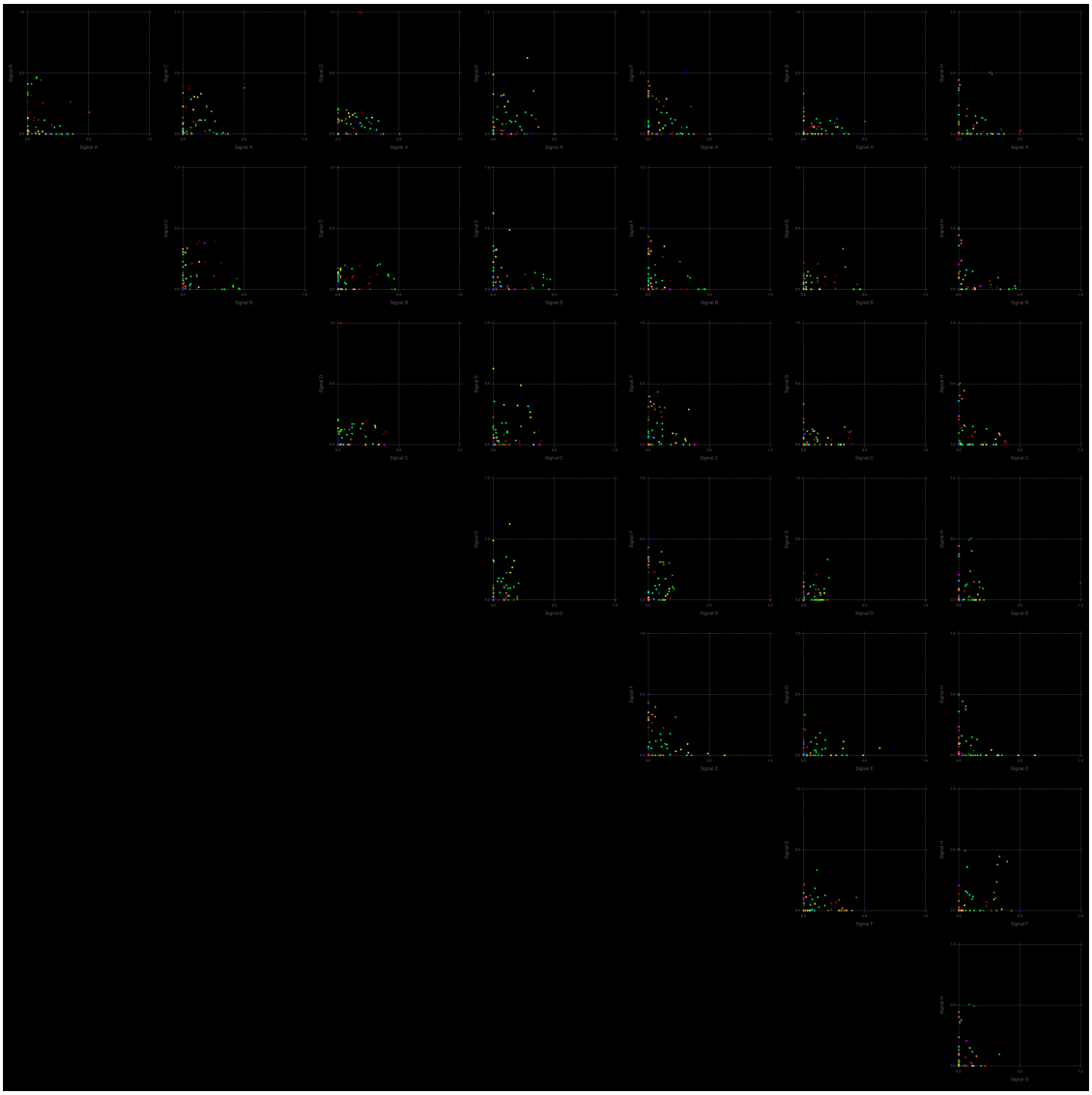


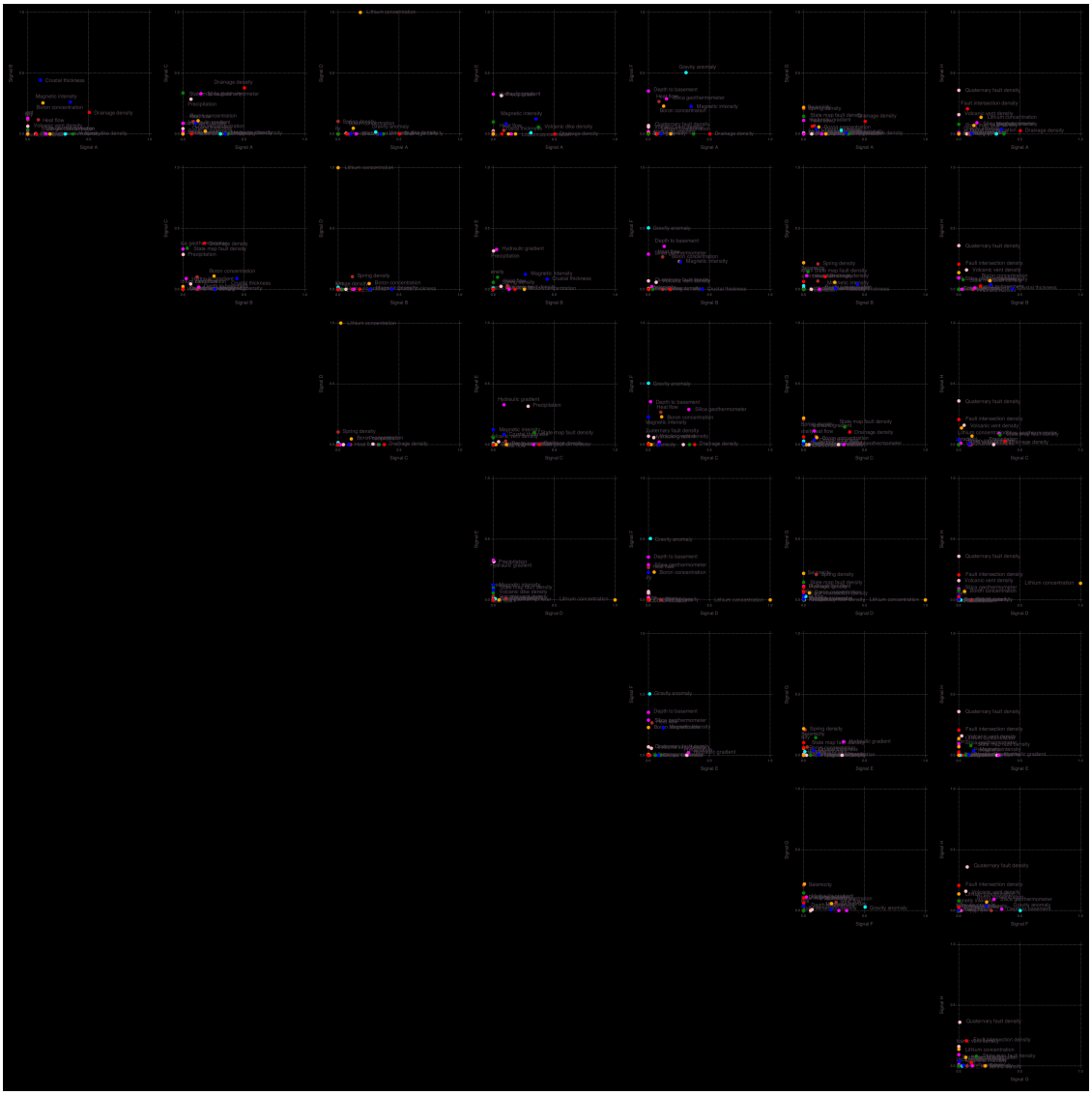

```
Info: Attributes (signals=8)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:322
Info: Signal A (S3) Count: 3
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal B (S1) Count: 3
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal C (S7) Count: 3
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal D (S5) Count: 2
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal E (S8) Count: 2
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal F (S2) Count: 2
```

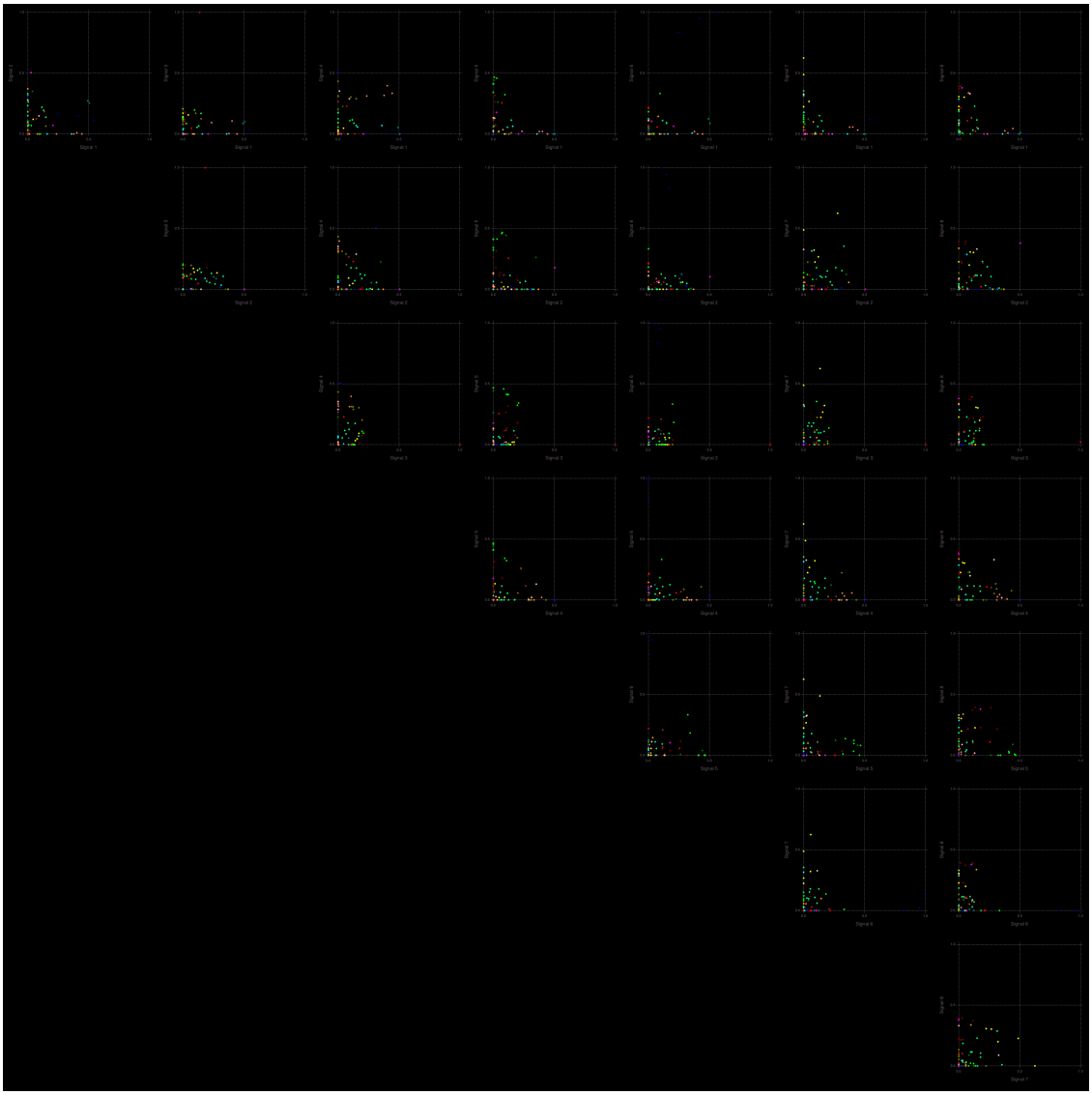
```
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal G (S6) Count: 2
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal H (S4) Count: 1
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal F -> A Count: 2
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal D -> B Count: 2
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal E -> C Count: 2
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal A -> D Count: 3
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal C -> E Count: 3
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal H -> F Count: 1
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal G -> G Count: 2
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal B -> H Count: 3
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal A (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal B (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal C (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal D (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal E (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal F (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal G (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal H (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
```

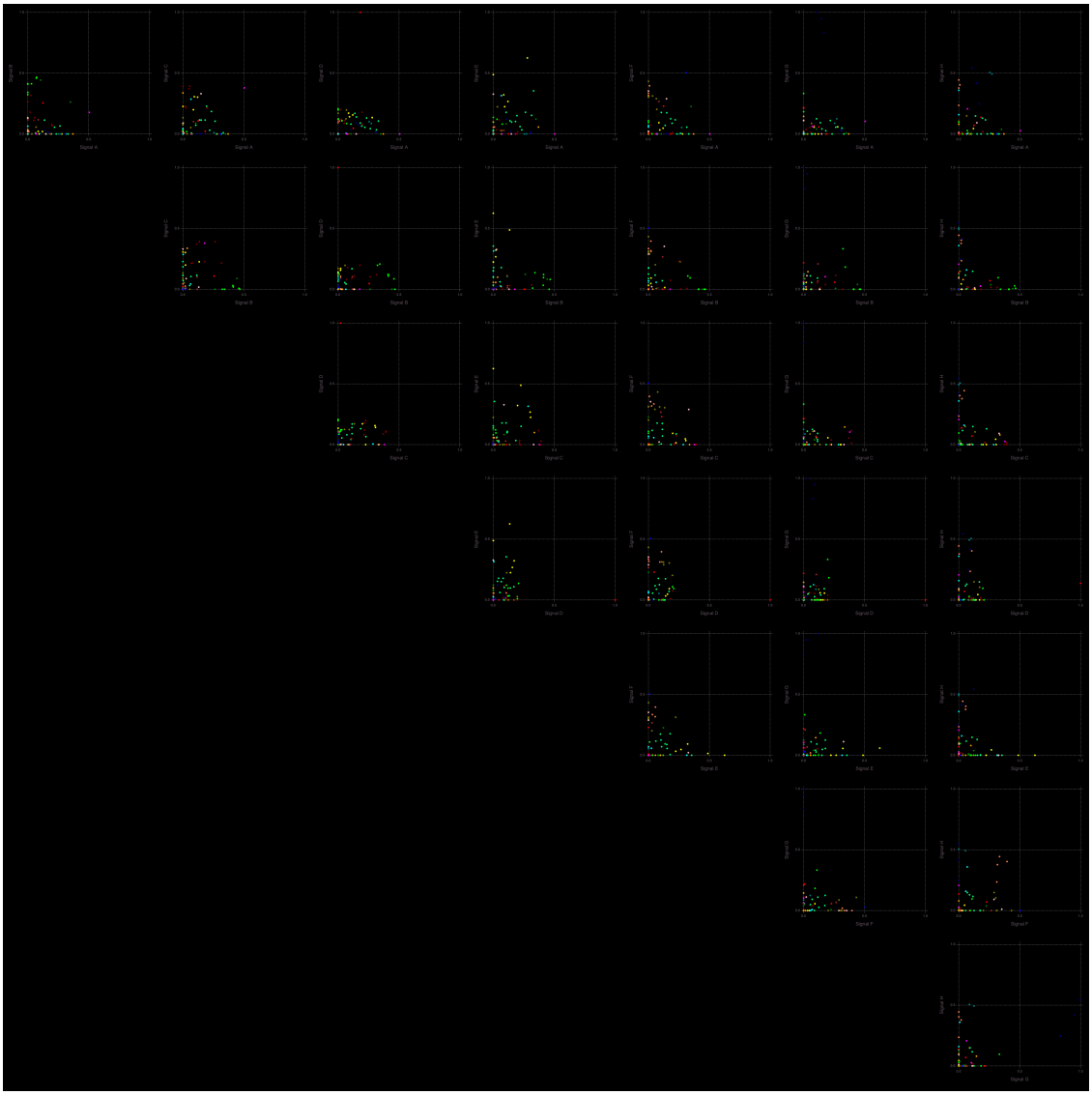










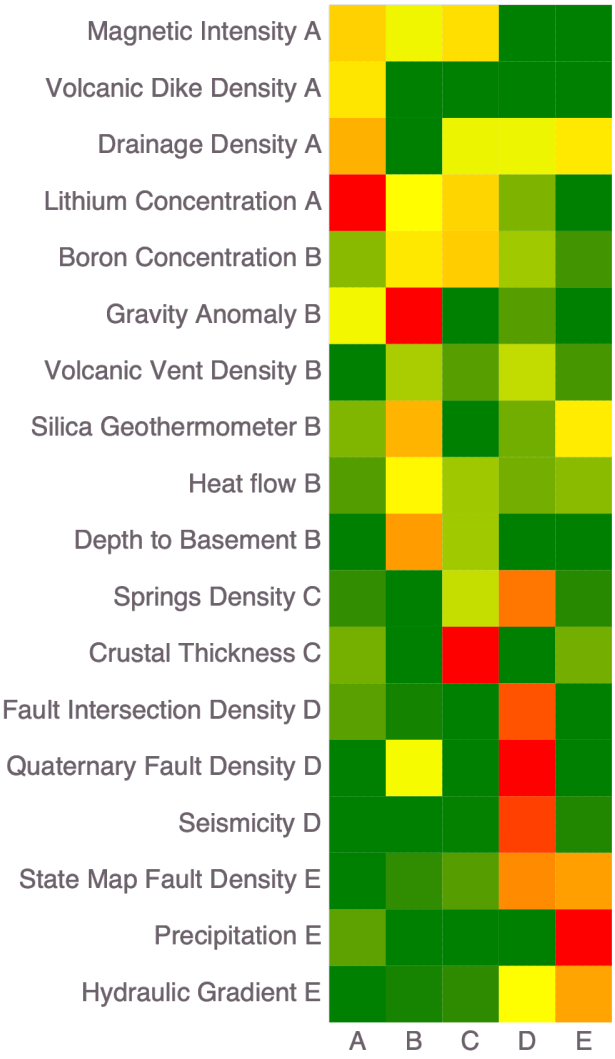


Analysis of the 5-signature solution The results for a solution with **5** signatures presented above will be further discussed here.

The geothermal attributes are clustered into **5** groups:

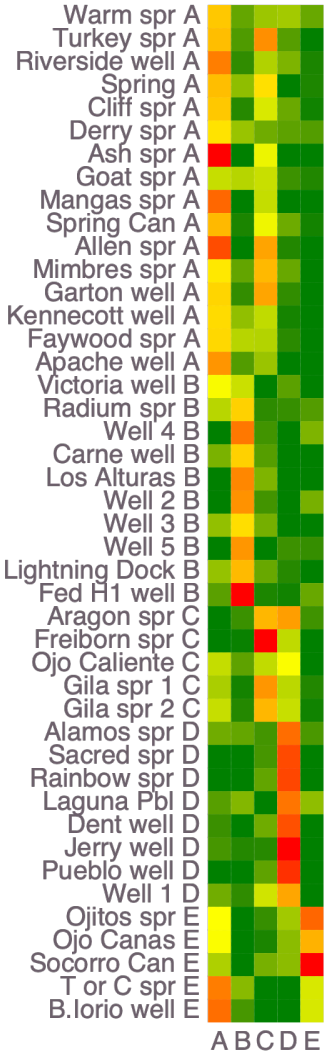
```
<iframe src="../results-case01/attributes-5-groups.txt" frameborder="0" height="400"
  width="95%"></iframe>
```

This grouping is based on analyses of the attribute matrix `W`:



The well locations are also clustered into **5** groups:

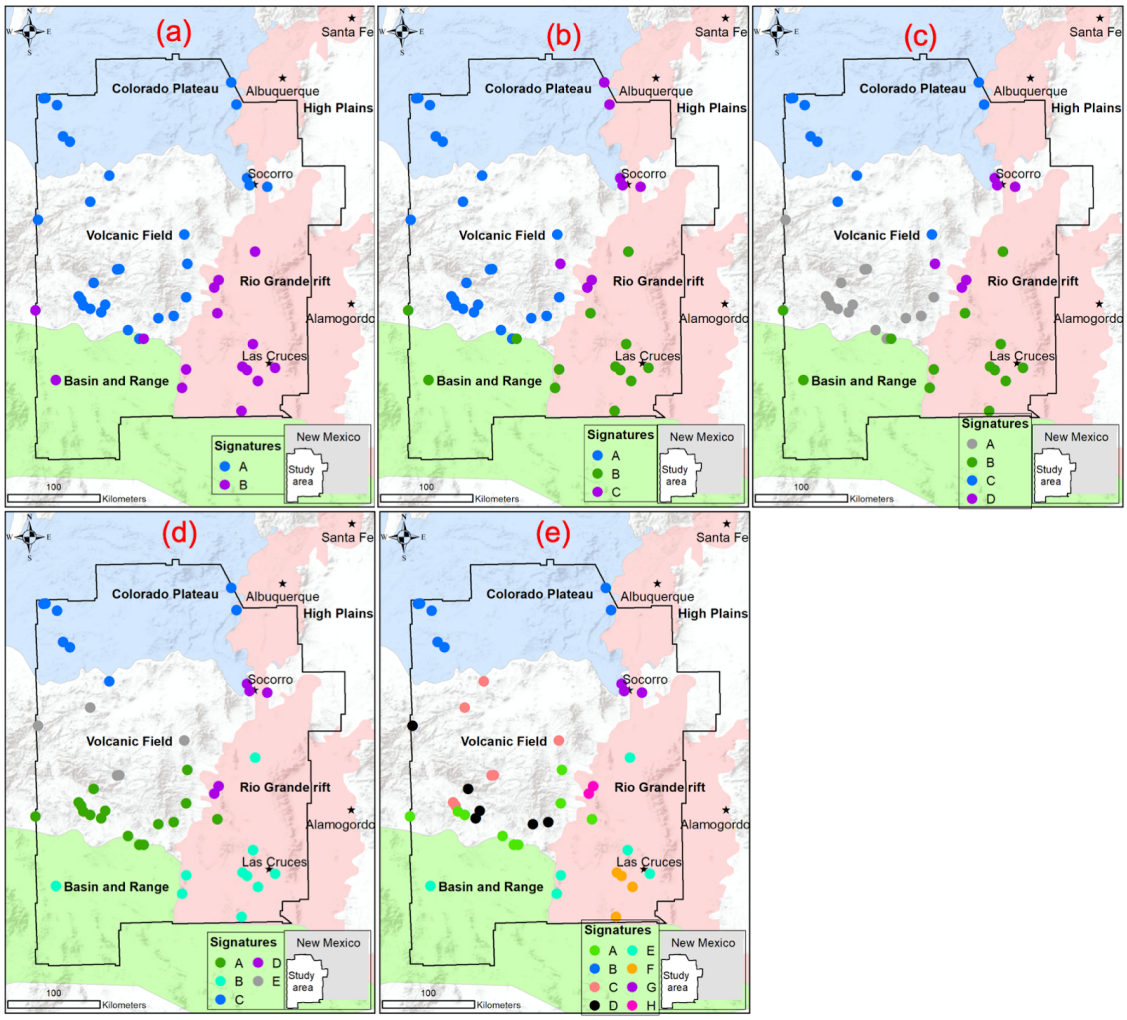
This grouping is based on analyses of the location matrix `H`:



The map `../figures-case01/locations-5-map.html` provides interacive visualization of the extracted location groups (the html file can be also openned with any browswer).

```
<iframe src="../figures-case01/locations-5-map.html" frameborder="0" height="400" width="50%">
```

Comparison of the ML solutions against the SWNM physiographic provinces Spatial association of the extracted signatures with the four physiographic provinces in SWNM is summarized here:



Clearly, the ML algorithm was able to blindly indentify the physiographic provinces associated with analyzed hydrogeothermal systems without providing any information about their location (coordinates).