prior_montecarlo

May 2, 2019

1 Run and process the prior monte carlo and pick a "truth" realization

In [1]:
```
import os
import shutil
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import flopy
import pyemu
```

```
flopy is installed in /Users/jeremyw/Dev/gw1876/activities_2day_mfm/notebooks/flopy
```

In [2]:
```
t_d = "template"
pst = pyemu.Pst(os.path.join(t_d,"freyberg.pst"))
```

1.0.1 Decide what pars are uncertain in the truth

We need to decide what our truth looks like - should the pilot points or the grid-scale pars be the source of spatial variability? or both?

In [3]:
```
par = pst.parameter_data
# grid pars
#should_fix = par.loc[par.pargp.apply(lambda x: "gr" in x),"parnme"]
# pp pars
#should_fix = par.loc[par.pargp.apply(lambda x: "pp" in x),"parnme"]
#pst.npar - should_fix.shape[0]
```

In [4]:
```
pe = pyemu.ParameterEnsemble.from_binary(pst=pst,filename=os.path.join(t_d,"prior.jcb")
#pe.loc[:,should_fix] = 1.0
pe.to_csv(os.path.join(t_d,"sweep_in.csv"))
```

```
new binary format detected...
```

1.0.2 run the prior ensemble in parallel locally

In [5]:
```
m_d = "master_prior_sweep"
pyemu.os_utils.start_slaves(t_d,"pestpp-swp","freyberg.pst",num_slaves=20,slave_root="
```

1.0.3 Load the output ensemble and plot a few things

```
In [6]: obs_df = pd.read_csv(os.path.join(m_d,"sweep_out.csv"),index_col=0)
        obs_df.shape
```

```
Out[6]: (200, 4465)
```

drop any failed runs

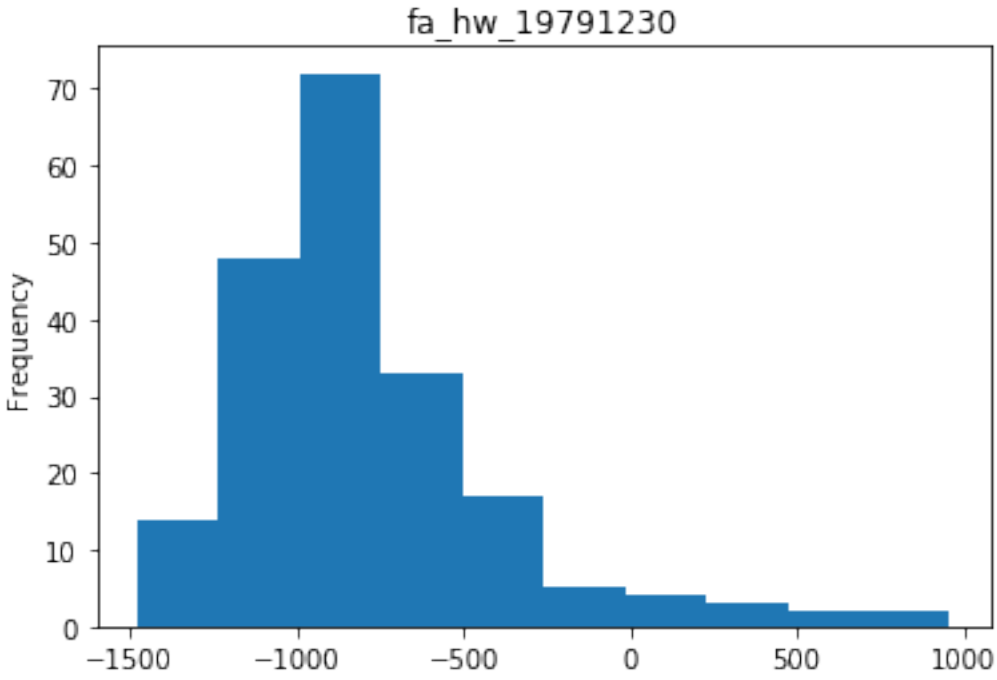
```
In [7]: obs_df = obs_df.loc[obs_df.failed_flag==0,:]
        obs_df.shape
```

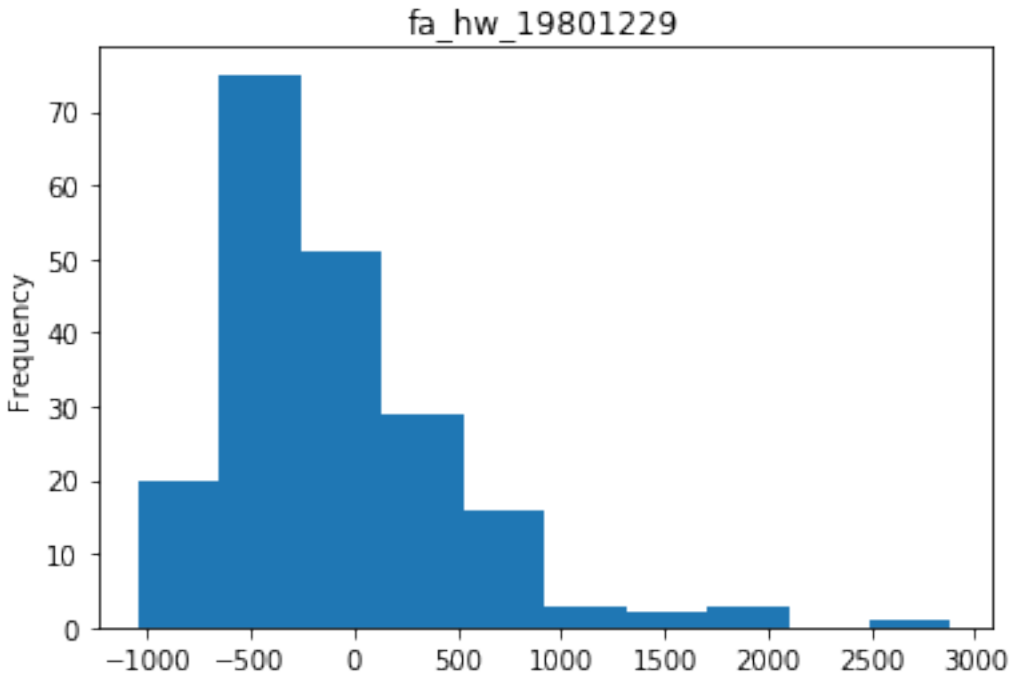
```
Out[7]: (200, 4465)
```

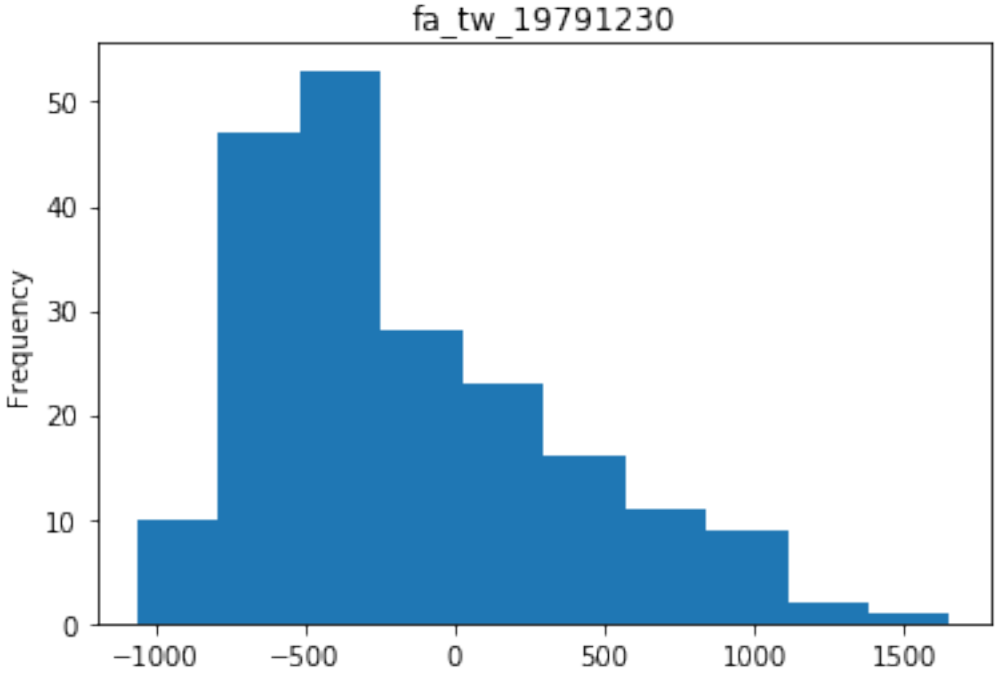
```
In [8]: fnames = pst.pestpp_options["forecasts"].split(',')
        fnames
```

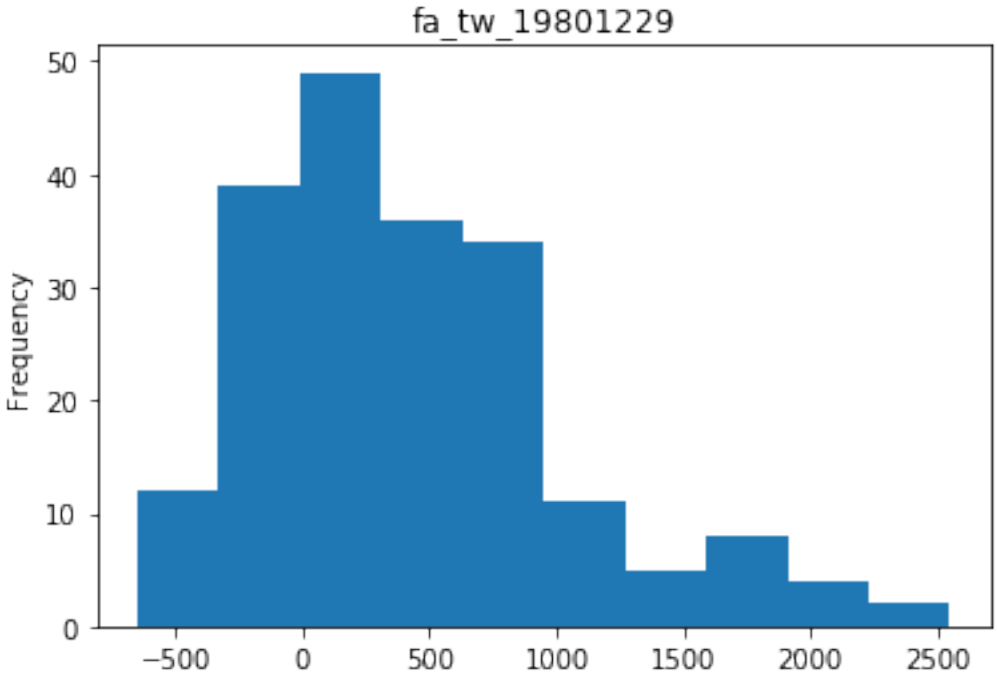
```
Out[8]: ['fa_hw_19791230',
         'fa_hw_19801229',
         'fa_tw_19791230',
         'fa_tw_19801229',
         'hds_00_013_002_000',
         'hds_00_013_002_001',
         'part_time',
         'part_status']
```

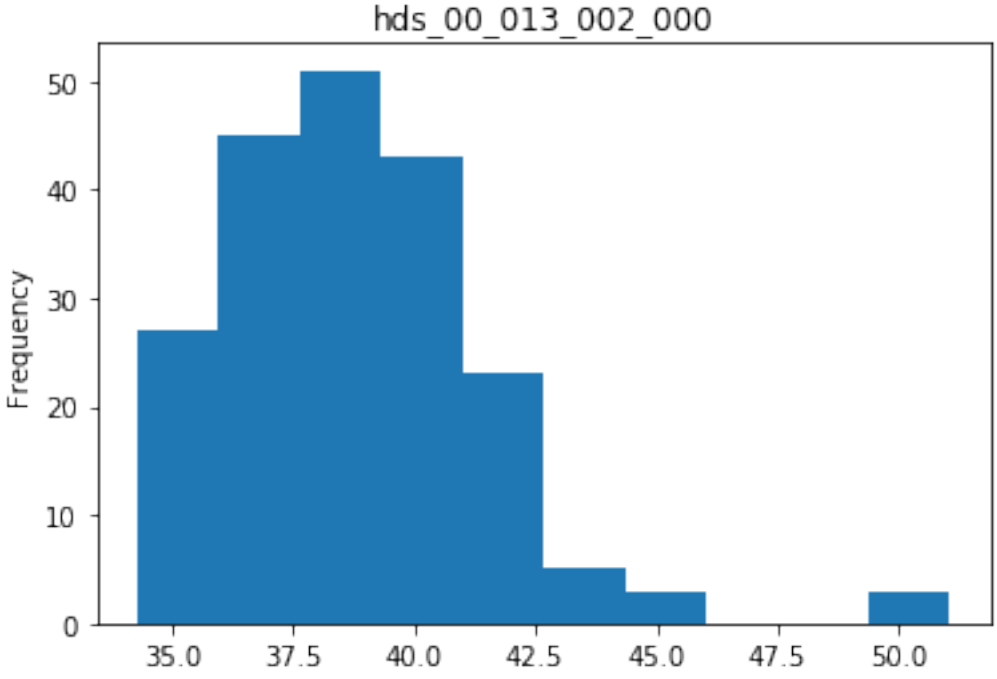
```
In [9]: for forecast in fnames:
            ax = obs_df.loc[:,forecast].plot(kind="hist")
            ax.set_title(forecast)
            plt.show()
```

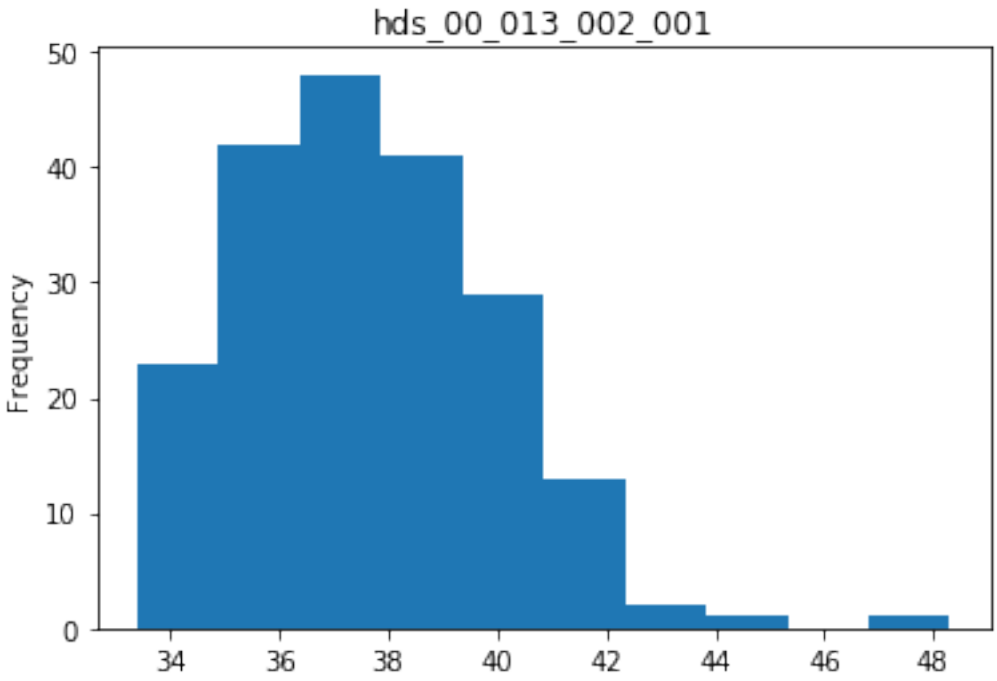


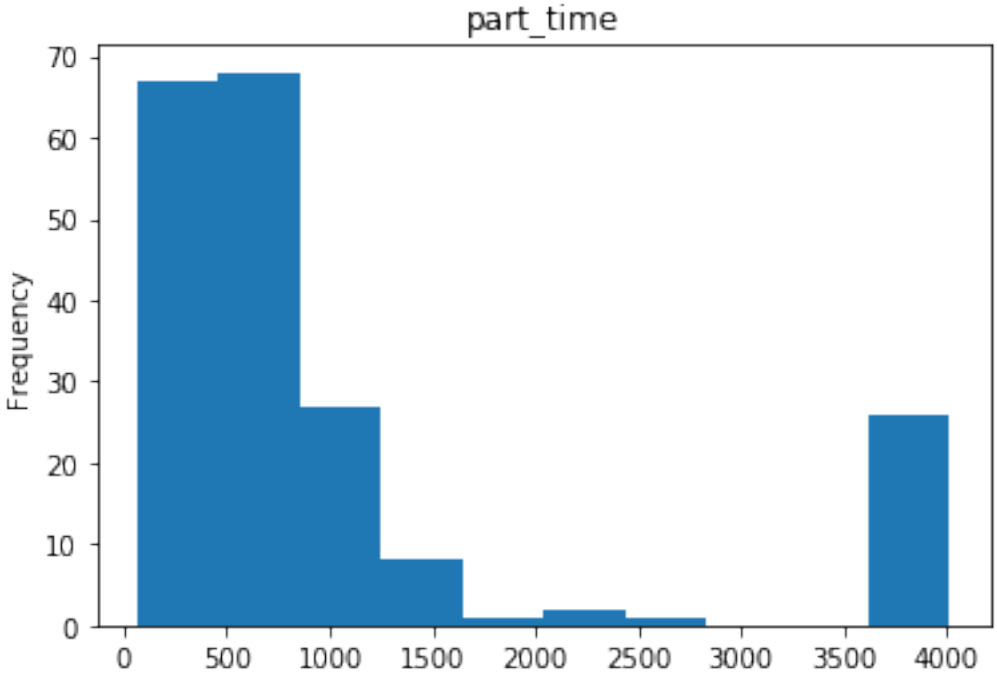

fa_hw_19801229
Frequency
70
60
50
40
30
20
10
0
−1000
−500
0
500
1000
1500
2000
2500
3000

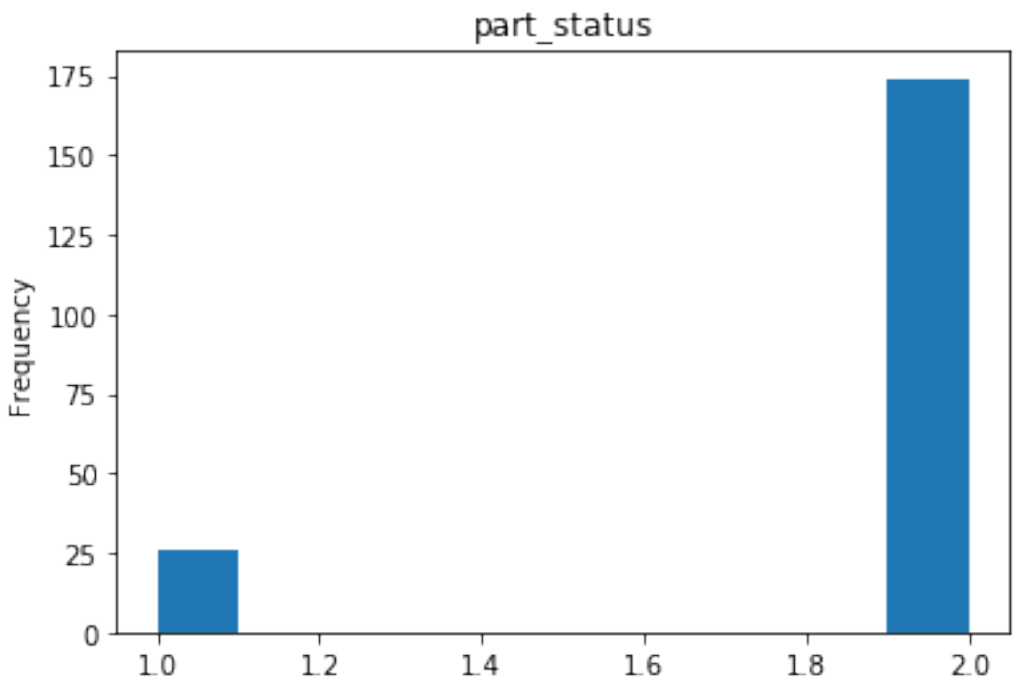

fa_tw_19791230
Frequency
50
40
30
20
10
0
−1000
−500
0
500
1000
1500


fa_tw_19801229
Frequency
50
40
30
20
10
0
−500
0
500
1000
1500
2000
2500


hds_00_013_002_000
Frequency
50
40
30
20
10
0
35.0
37.5
40.0
42.5
45.0
47.5
50.0

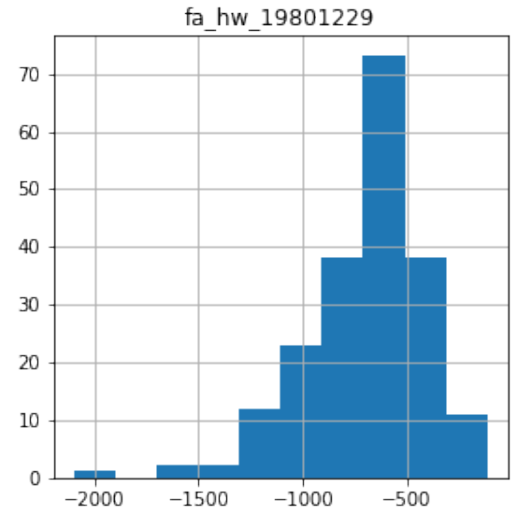

hds_00_013_002_001
Frequency
0
10
20
30
40
50
34
36
38
40
42
44
46
48

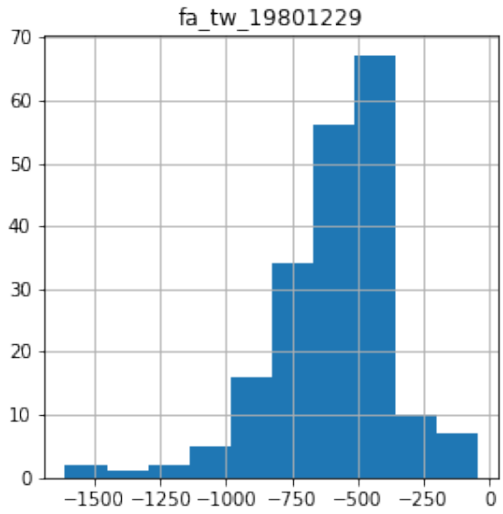

part_time
Frequency
0
10
20
30
40
50
60
70
0
500
1000
1500
2000
2500
3000
3500
4000

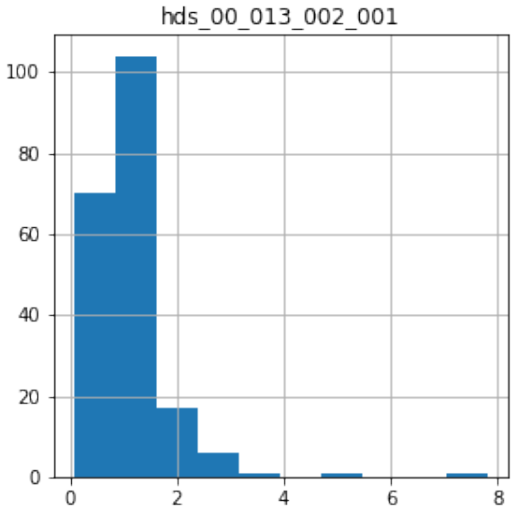


We see that under scenario conditions, many more realizations for the flow to the aquifer in the headwaters are postive (as expected). Lets difference these two:

```
In [10]: sfnames = [f for f in fnames if "1980" in f or "_001" in f]
         hfnames = [f for f in fnames if "1979" in f or "_000" in f]
         diff = obs_df.loc[:,hfnames].values - obs_df.loc[:,sfnames].values
         diff = pd.DataFrame(diff,columns=sfnames)
         diff.hist(figsize=(10,10))

Out[10]: array([[<matplotlib.axes._subplots.AxesSubplot object at 0x181b645390>,
                 <matplotlib.axes._subplots.AxesSubplot object at 0x181ba725c0>],
                [<matplotlib.axes._subplots.AxesSubplot object at 0x181ba8aac8>,
                 <matplotlib.axes._subplots.AxesSubplot object at 0x181baa7080>]],
               dtype=object)
```







We now see that the most extreme scenario yields a large decrease in flow from the aquifer to the headwaters (the most negative value)

1.0.4 setting the "truth"

We just need to replace the observed values (`obsval`) in the control file with the outputs for one of the realizations on `obs_df`. In this way, we now have the nonzero values for history matching, but also the `truth` values for comparing how we are doing with other unobserved quantities. Im going to pick a realization that yields an "average" variability of the observed gw levels:

```
In [11]: # choose the realization with a low historic gw to sw headwater flux
         hist_swgw = obs_df.loc[:,"fa_hw_19791230"].sort_values()
         idx = hist_swgw.index[10]
         idx
```

```
Out[11]: 26

In [12]: obs_df.loc[idx,pst.nnz_obs_names]

Out[12]: fo_39_19791230        11200.000000
         hds_00_002_009_000       35.298595
         hds_00_002_015_000       34.651405
         hds_00_003_008_000       35.381458
         hds_00_009_001_000       36.549999
         hds_00_013_010_000       34.945221
         hds_00_015_016_000       34.754948
         hds_00_021_010_000       34.856949
         hds_00_022_015_000       34.468357
         hds_00_024_004_000       35.140781
         hds_00_026_006_000       34.859554
         hds_00_029_015_000       34.306465
         hds_00_033_007_000       33.894123
         hds_00_034_010_000       33.719563
         Name: 26, dtype: float64
```

Lets see how our selected truth does with the swgw forecasts:

```
In [13]: obs_df.loc[idx,fnames]

Out[13]: fa_hw_19791230       -1265.704600
         fa_hw_19801229        -555.443500
         fa_tw_19791230        -257.454120
         fa_tw_19801229         210.098000
         hds_00_013_002_000      36.337082
         hds_00_013_002_001      35.521656
         part_time             4015.000000
         part_status              1.000000
         Name: 26, dtype: float64

In [14]: pst = pyemu.Pst(os.path.join(t_d,"freyberg.pst"))
         obs = pst.observation_data
         obs.loc[:,"obsval"] = obs_df.loc[idx,pst.obs_names]
         obs.loc[obs.obgnme=="calhead","weight"] = 5.0
         obs.loc[obs.obgnme=="calflux","weight"] = 0.035
         obs.weight.value_counts()

Out[14]: 0.000    4422
         5.000      13
         0.035       1
         Name: weight, dtype: int64
```

Now, it is custom to add noise to the observed values…we will use the classic Gaussian noise…zero mean and standard deviation of 1 over the weight

```
In [15]: # this should give the same standard normal draws each time
         np.random.seed(seed=0)
         snd = np.random.randn(pst.nnz_obs)
         snd

Out[15]: array([ 1.76405235,  0.40015721,  0.97873798,  2.2408932 ,  1.86755799,
                -0.97727788,  0.95008842, -0.15135721, -0.10321885,  0.4105985 ,
                 0.14404357,  1.45427351,  0.76103773,  0.12167502])

In [16]: noise = snd * 1./obs.loc[pst.nnz_obs_names,"weight"]
         noise

Out[16]: obsnme
         fo_39_19791230        50.401496
         hds_00_002_009_000     0.080031
         hds_00_002_015_000     0.195748
         hds_00_003_008_000     0.448179
         hds_00_009_001_000     0.373512
         hds_00_013_010_000    -0.195456
         hds_00_015_016_000     0.190018
         hds_00_021_010_000    -0.030271
         hds_00_022_015_000    -0.020644
         hds_00_024_004_000     0.082120
         hds_00_026_006_000     0.028809
         hds_00_029_015_000     0.290855
         hds_00_033_007_000     0.152208
         hds_00_034_010_000     0.024335
         Name: weight, dtype: float64
```

Only run this block once!!!

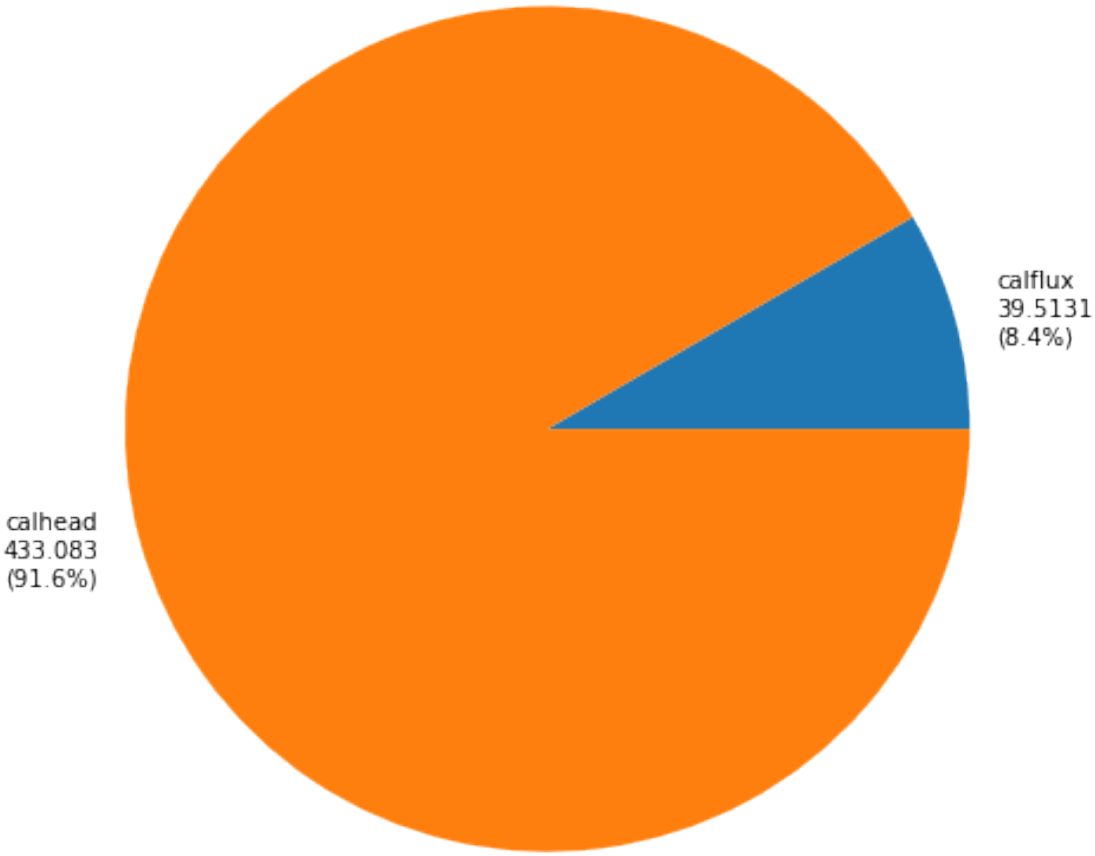
```
In [17]: pst.observation_data.loc[noise.index,"obsval"] += noise
         pst.write(os.path.join(t_d,"freyberg.pst"))
         pyemu.os_utils.run("pestpp-ies freyberg.pst",cwd=t_d)

In [18]: pst = pyemu.Pst(os.path.join(t_d,"freyberg.pst"))
         print(pst.phi)
         pst.res.loc[pst.nnz_obs_names,:]

472.59650318891005


Out[18]:                                    name    group      measured      modelled  \
         name
         fo_39_19791230          fo_39_19791230  calflux  11250.401496  11430.000000
         hds_00_002_009_000  hds_00_002_009_000  calhead     35.378627     37.107498
         hds_00_002_015_000  hds_00_002_015_000  calhead     34.847153     35.045185
         hds_00_003_008_000  hds_00_003_008_000  calhead     35.829637     37.397289
         hds_00_009_001_000  hds_00_009_001_000  calhead     36.923511     39.546417
```

```
hds_00_013_010_000  hds_00_013_010_000  calhead     34.749765     35.571774
hds_00_015_016_000  hds_00_015_016_000  calhead     34.944965     34.835716
hds_00_021_010_000  hds_00_021_010_000  calhead     34.826677     35.386250
hds_00_022_015_000  hds_00_022_015_000  calhead     34.447713     34.577492
hds_00_024_004_000  hds_00_024_004_000  calhead     35.222901     36.760464
hds_00_026_006_000  hds_00_026_006_000  calhead     34.888363     35.896149
hds_00_029_015_000  hds_00_029_015_000  calhead     34.597320     34.453842
hds_00_033_007_000  hds_00_033_007_000  calhead     34.046331     34.678810
hds_00_034_010_000  hds_00_034_010_000  calhead     33.743898     34.118073
```

name	residual	weight
fo_39_19791230	-179.598504	0.035
hds_00_002_009_000	-1.728871	5.000
hds_00_002_015_000	-0.198032	5.000
hds_00_003_008_000	-1.567652	5.000
hds_00_009_001_000	-2.622906	5.000
hds_00_013_010_000	-0.822008	5.000
hds_00_015_016_000	0.109249	5.000
hds_00_021_010_000	-0.559572	5.000
hds_00_022_015_000	-0.129778	5.000
hds_00_024_004_000	-1.537563	5.000
hds_00_026_006_000	-1.007786	5.000
hds_00_029_015_000	0.143478	5.000
hds_00_033_007_000	-0.632479	5.000
hds_00_034_010_000	-0.374175	5.000

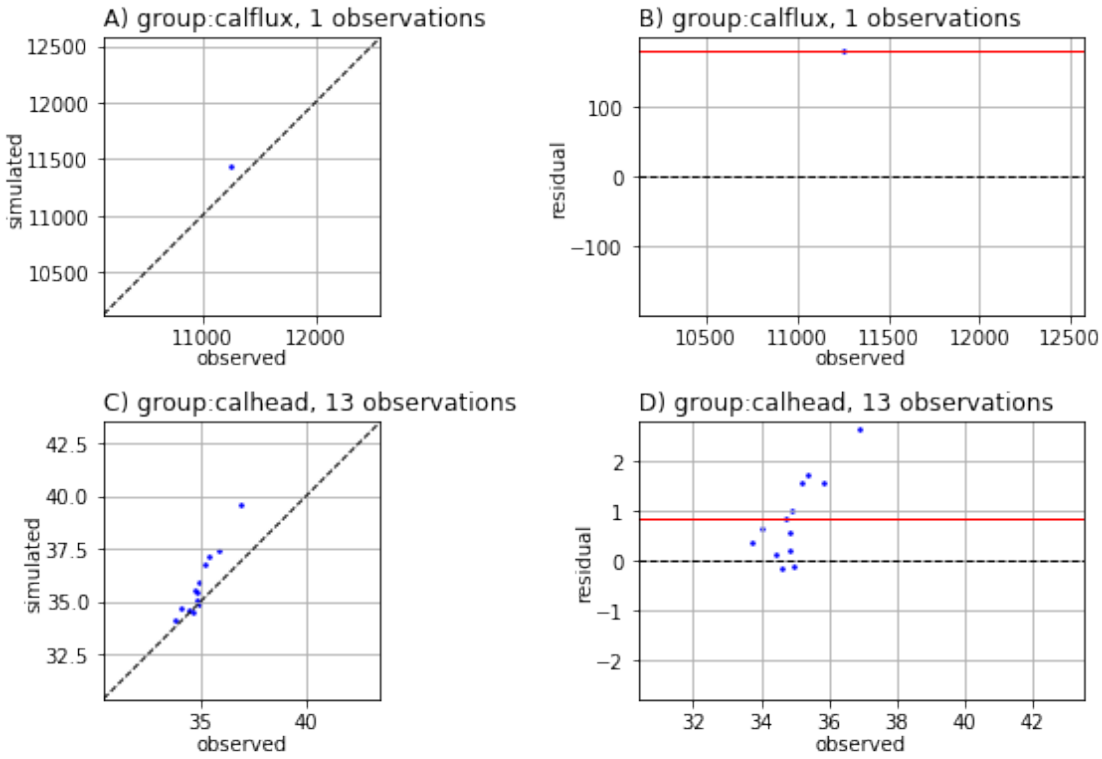
In [19]:
```
pst.phi_components
pst.plot(kind='phi_pie')
```

Out[19]:
```
<matplotlib.axes._subplots.AxesSubplot at 0x181ee629b0>
```




```
In [20]: figs = pst.plot(kind="1to1")
```

```
<Figure size 576x756 with 0 Axes>
```



Publication ready figs - oh snap!

Just to make sure we have everything working right, we should be able to load the truth parameters, run the model once and have a `phi` equivalent to the noise vector:

In [21]:
```
par_df = pd.read_csv(os.path.join(m_d,"sweep_in.csv"),index_col=0)
pst.parameter_data.loc[:,"parval1"] = par_df.loc[idx,pst.par_names]
pst.write(os.path.join(m_d,"test.pst"))
pyemu.os_utils.run("pestpp-ies.exe test.pst",cwd=m_d)
pst = pyemu.Pst(os.path.join(m_d,"test.pst"))
print(pst.phi)
pst.res.loc[pst.nnz_obs_names,:]
```

```
17.528847256189565
```

Out[21]:

	name	group	measured	modelled	residual	weight
name						
fo_39_19791230	fo_39_19791230	calflux	11250.401496	11200.000000	50.401496	0.035
hds_00_002_009_000	hds_00_002_009_000	calhead	35.378627	35.298595	0.080031	5.000
hds_00_002_015_000	hds_00_002_015_000	calhead	34.847153	34.651405	0.195748	5.000
hds_00_003_008_000	hds_00_003_008_000	calhead	35.829637	35.381458	0.448179	5.000
hds_00_009_001_000	hds_00_009_001_000	calhead	36.923511	36.549999	0.373512	5.000
hds_00_013_010_000	hds_00_013_010_000	calhead	34.749765	34.945221	-0.195456	5.000
hds_00_015_016_000	hds_00_015_016_000	calhead	34.944965	34.754948	0.190018	5.000
hds_00_021_010_000	hds_00_021_010_000	calhead	34.826677	34.856949	-0.030271	5.000
hds_00_022_015_000	hds_00_022_015_000	calhead	34.447713	34.468357	-0.020644	5.000
hds_00_024_004_000	hds_00_024_004_000	calhead	35.222901	35.140781	0.082120	5.000
hds_00_026_006_000	hds_00_026_006_000	calhead	34.888363	34.859554	0.028809	5.000
hds_00_029_015_000	hds_00_029_015_000	calhead	34.597320	34.306465	0.290855	5.000
hds_00_033_007_000	hds_00_033_007_000	calhead	34.046331	33.894123	0.152208	5.000
hds_00_034_010_000	hds_00_034_010_000	calhead	33.743898	33.719563	0.024335	5.000

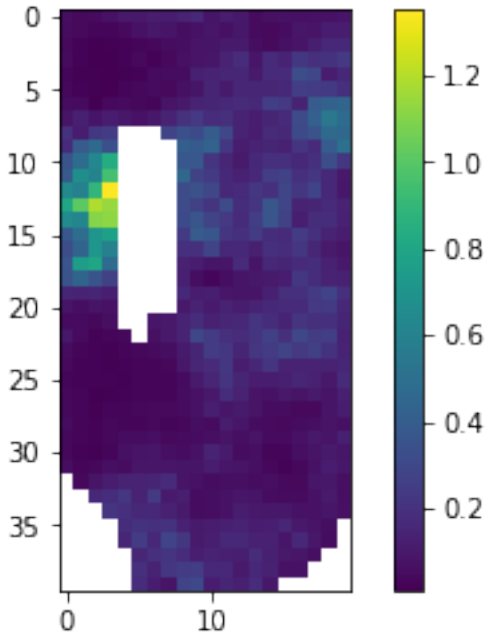
The residual should be exactly the noise values from above.Lets load the model (that was just run using the true pars) and check some things

In [22]:
```
m = flopy.modflow.Modflow.load("freyberg.nam",model_ws=m_d)
```

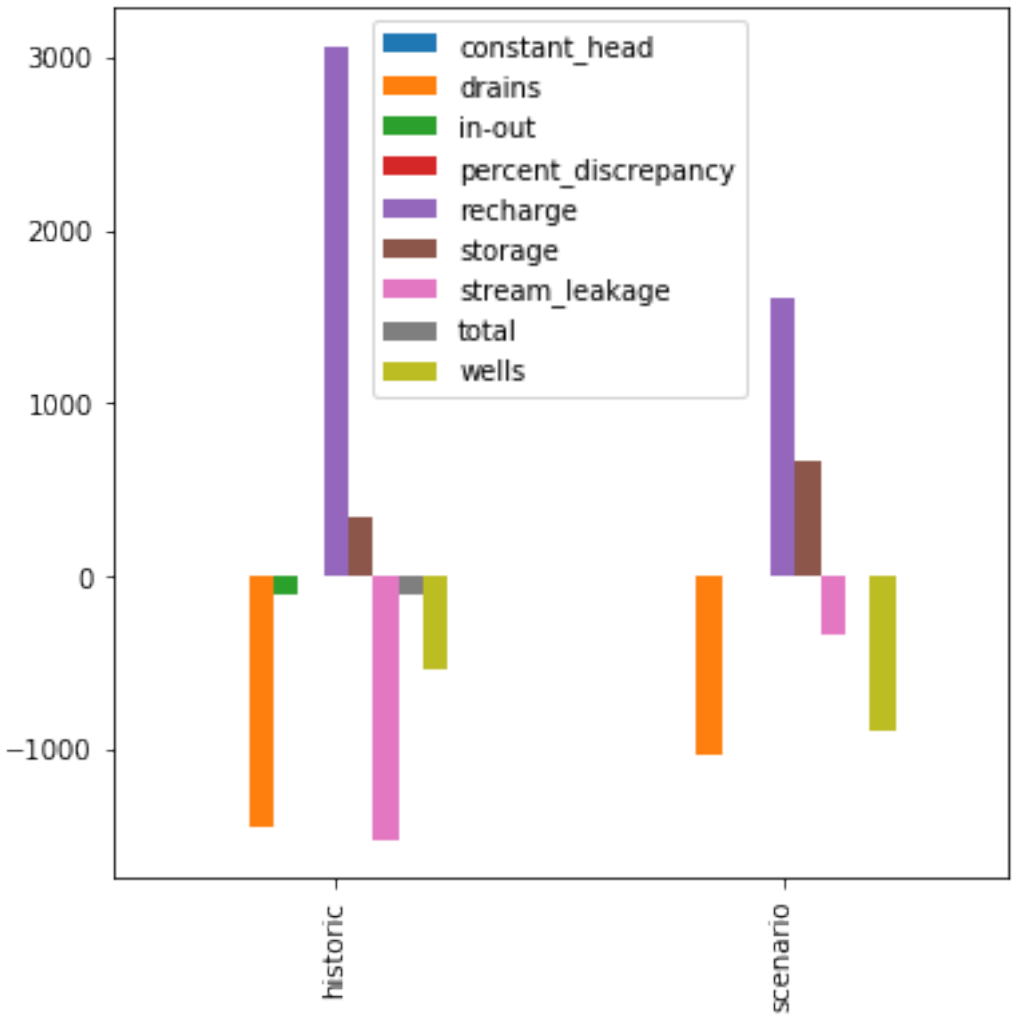
In [23]:
```
a = m.upw.vka[1].array
#a = m.rch.rech[0].array
a = np.ma.masked_where(m.bas6.ibound[0].array==0,a)
print(a.min(),a.max())
c = plt.imshow(a)
plt.colorbar(c)
```

```
0.009521352 1.351456
```

Out[23]: <matplotlib.colorbar.Colorbar at 0x181c333748>



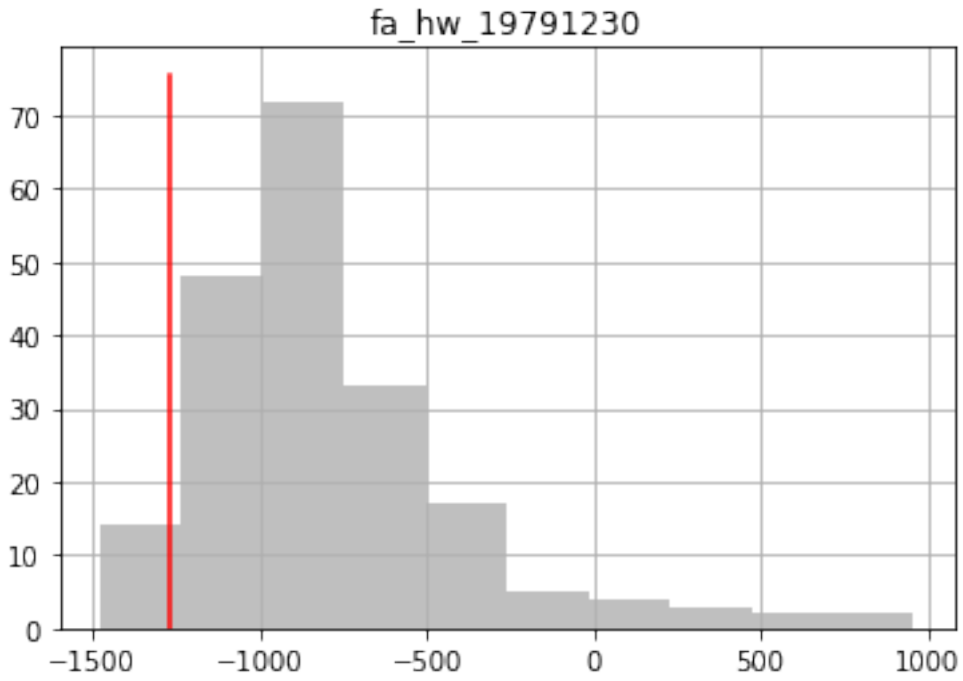
In [24]:
```
lst = flopy.utils.MfListBudget(os.path.join(m_d,"freyberg.list"))
df = lst.get_dataframes(diff=True)[0]
ax = df.plot(kind="bar",figsize=(6,6))
a = ax.set_xticklabels(["historic","scenario"],rotation=90)
```

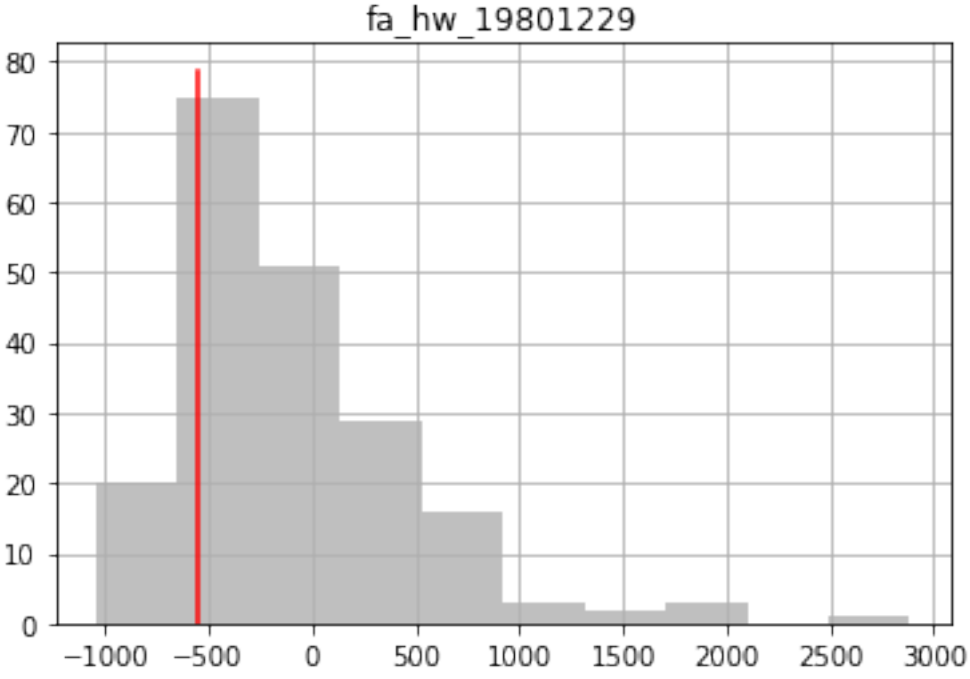


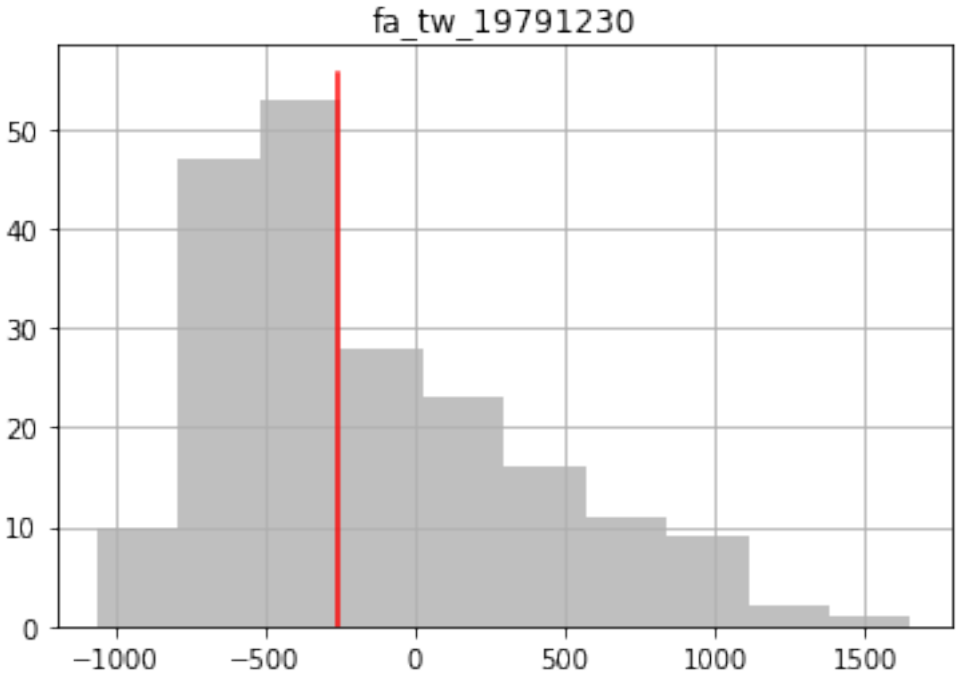
1.0.5 see how our existing observation ensemble compares to the truth

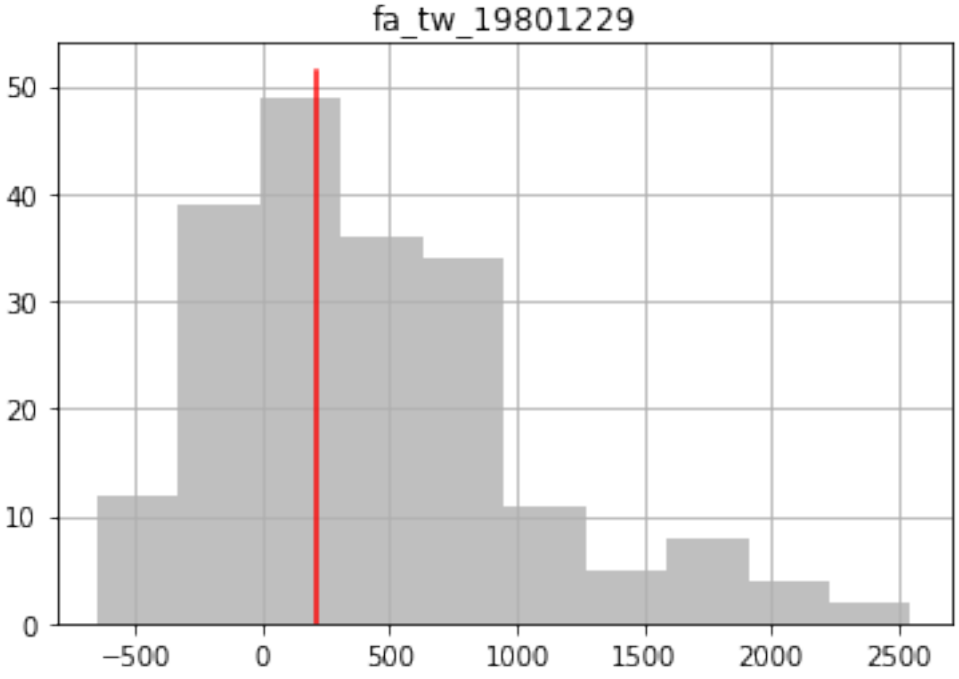
sw-gw outputs:

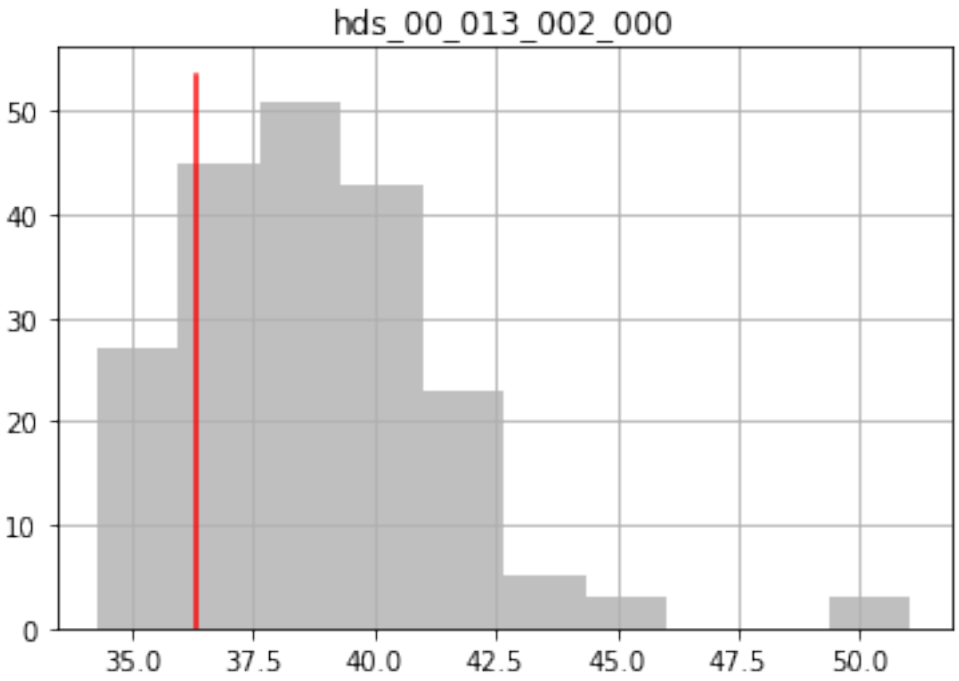
```
In [25]: obs = pst.observation_data

         for forecast in fnames:
             ax = plt.subplot(111)
             obs_df.loc[:,forecast].hist(ax=ax,color="0.5",alpha=0.5)
             ax.plot([obs.loc[forecast,"obsval"],obs.loc[forecast,"obsval"]],ax.get_ylim(),"r"
             ax.set_title(forecast)
             plt.show()
```

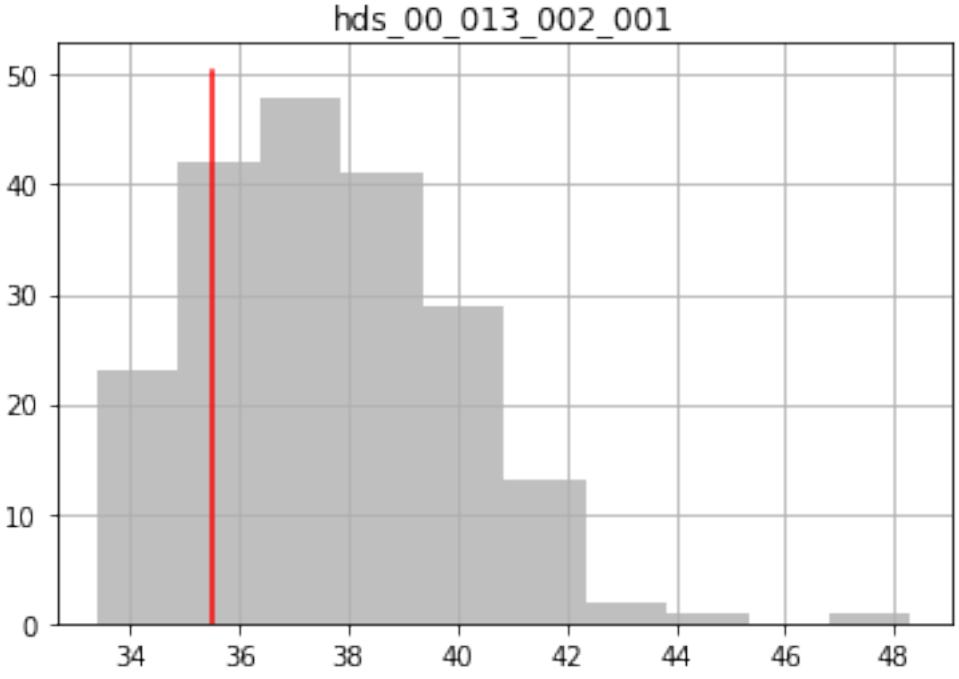

fa_hw_19791230
70
60
50
40
30
20
10
0
−1500
−1000
−500
0
500
1000

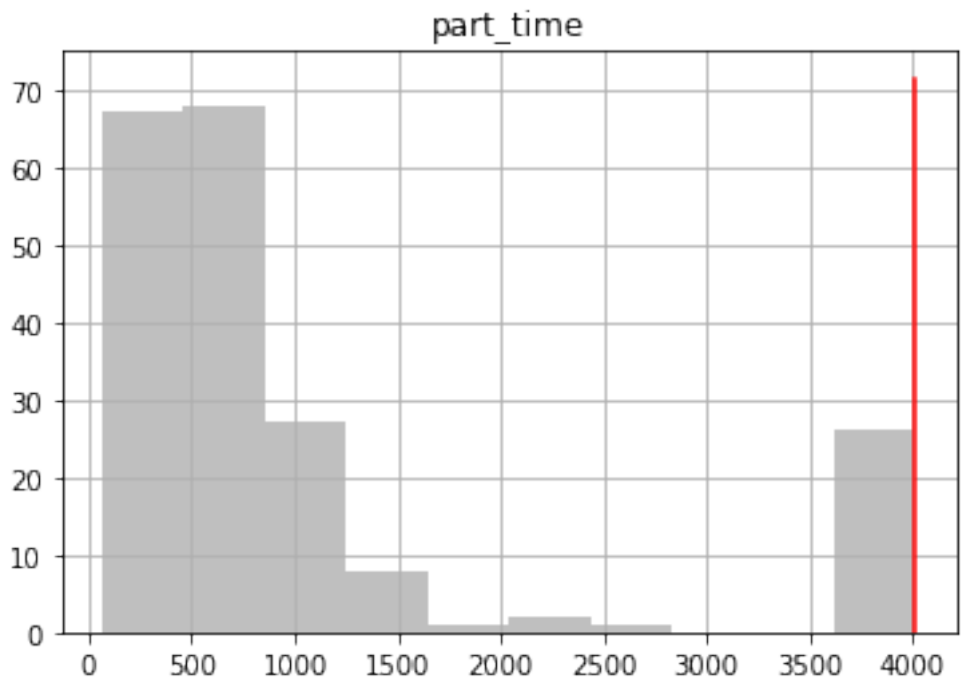

fa_hw_19801229
80
70
60
50
40
30
20
10
0
−1000
−500
0
500
1000
1500
2000
2500
3000

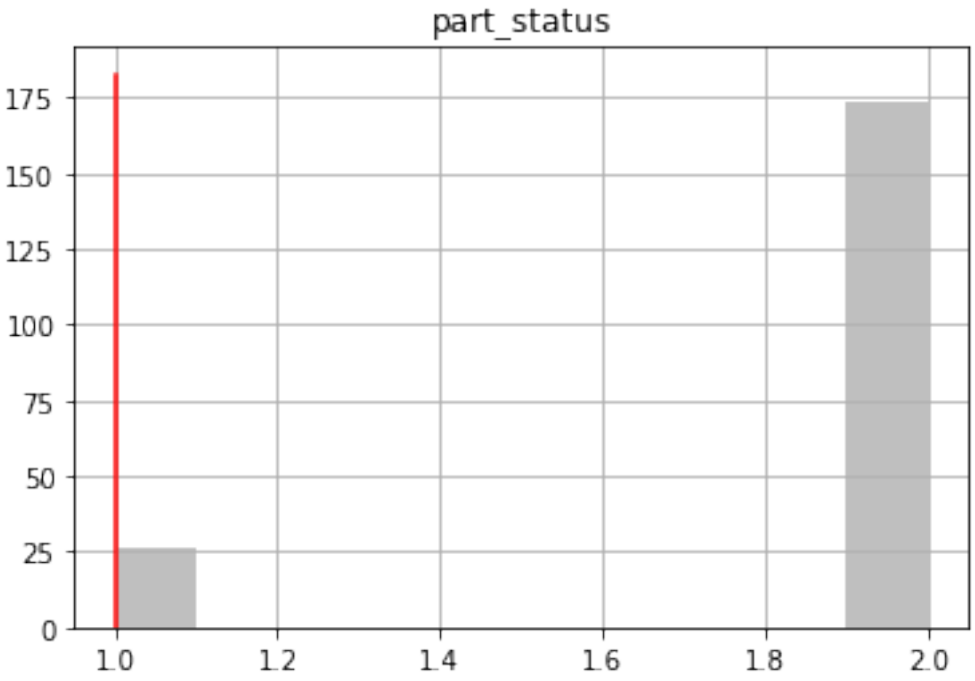

fa_tw_19791230
50
40
30
20
10
0
−1000
−500
0
500
1000
1500


fa_tw_19801229
50
40
30
20
10
0
−500
0
500
1000
1500
2000
2500


hds_00_013_002_000
50
40
30
20
10
0
35.0
37.5
40.0
42.5
45.0
47.5
50.0

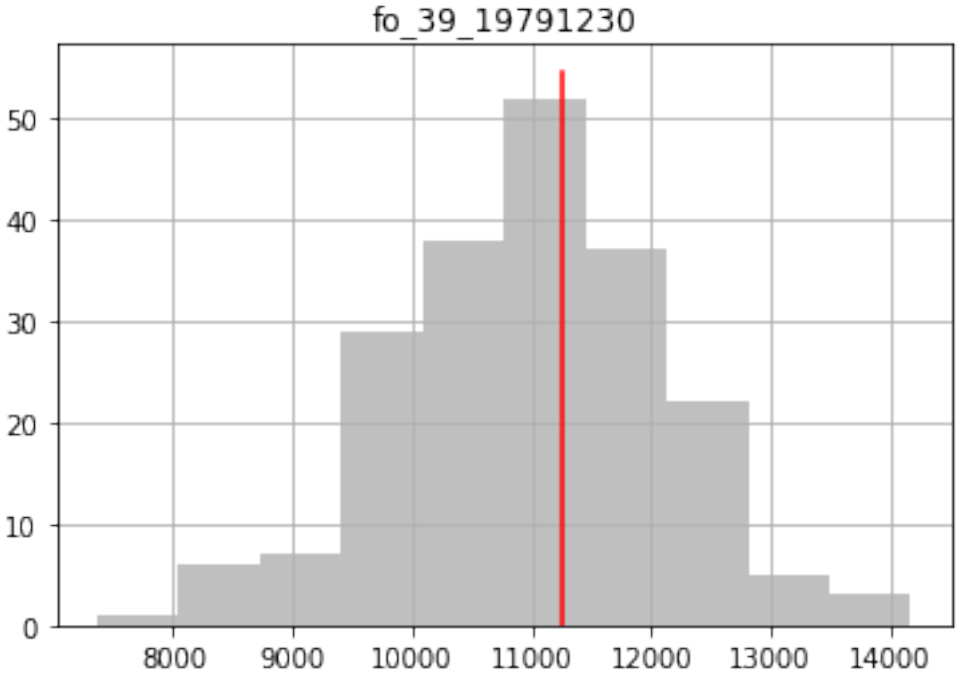

hds_00_013_002_001
50
40
30
20
10
0
34
36
38
40
42
44
46
48

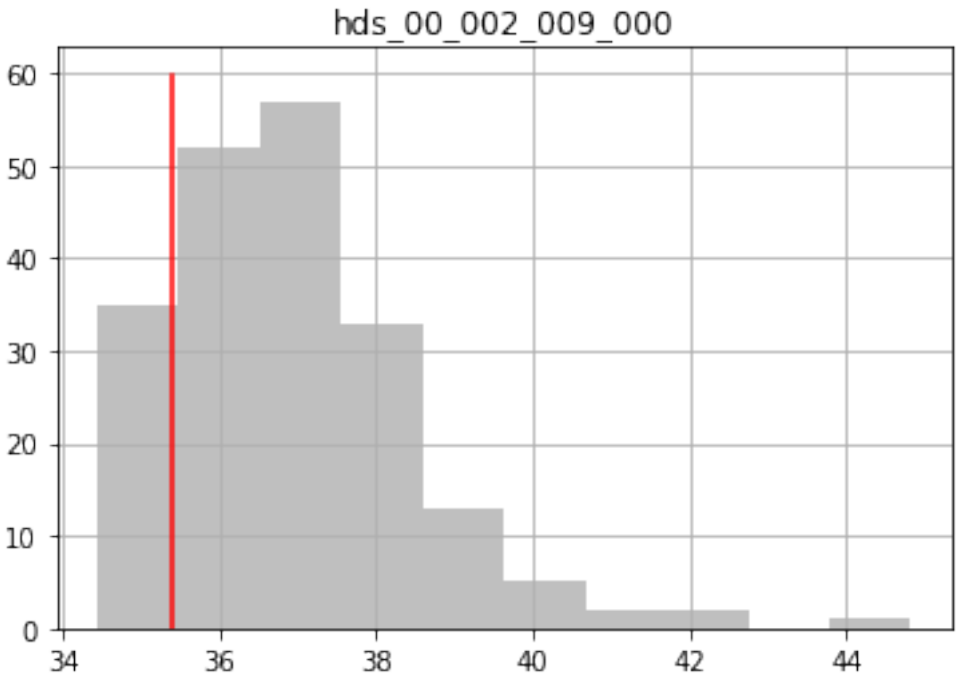


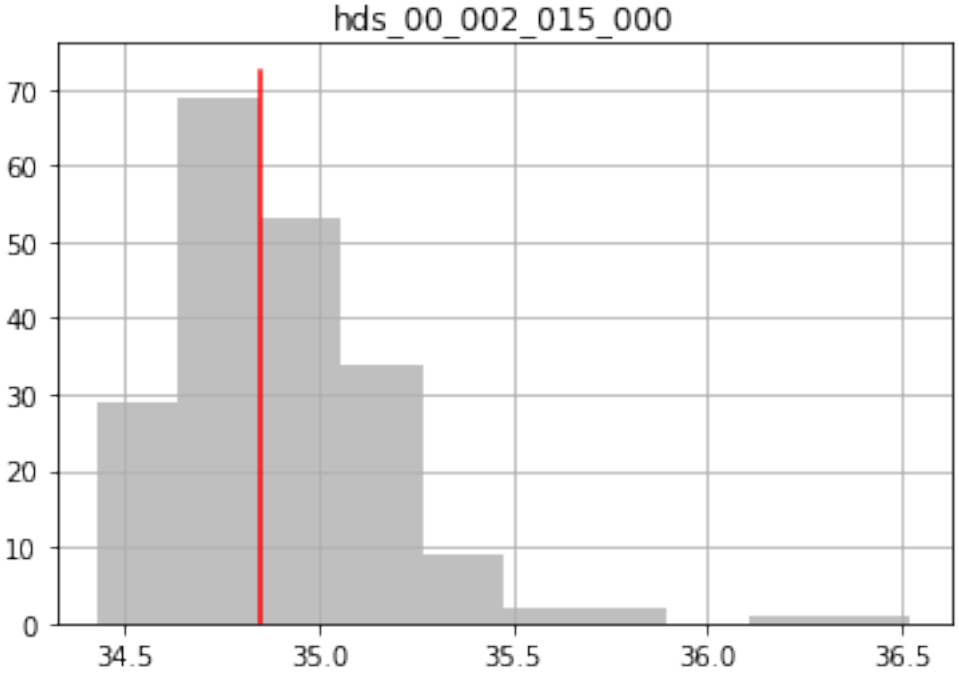


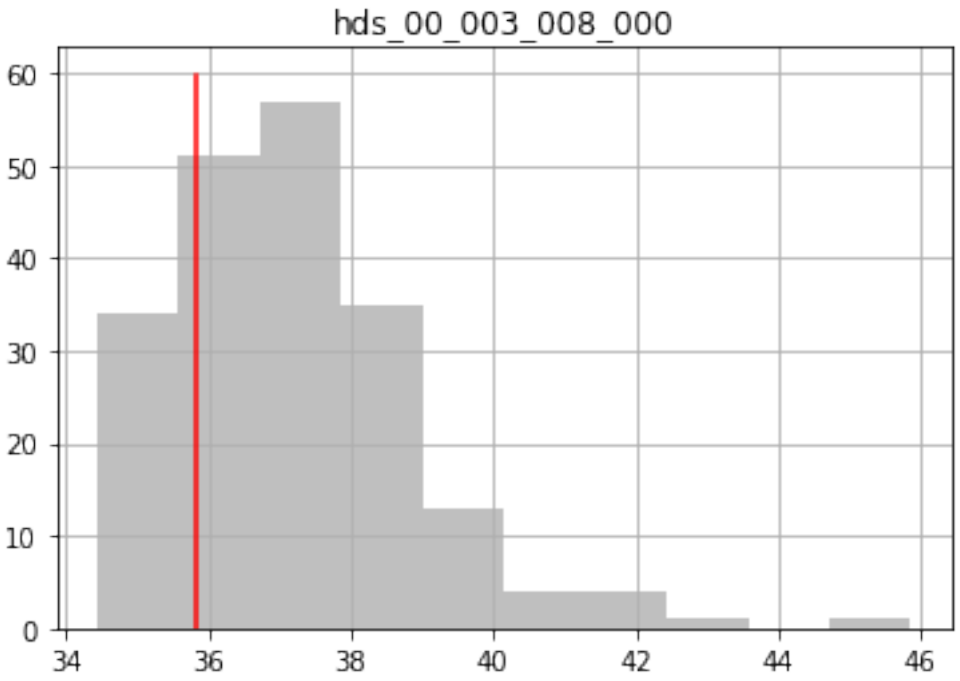
observations:

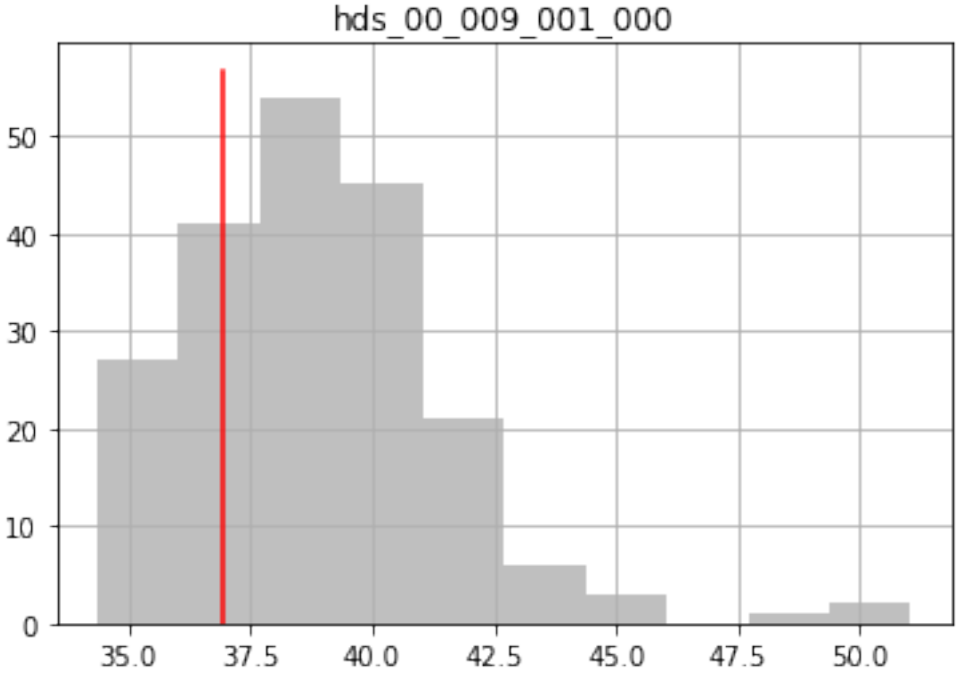
```
In [26]: for oname in pst.nnz_obs_names:
             ax = plt.subplot(111)
             obs_df.loc[:,oname].hist(ax=ax,color="0.5",alpha=0.5)
             ax.plot([obs.loc[oname,"obsval"],obs.loc[oname,"obsval"]],ax.get_ylim(),"r")
             ax.set_title(oname)
             plt.show()
```

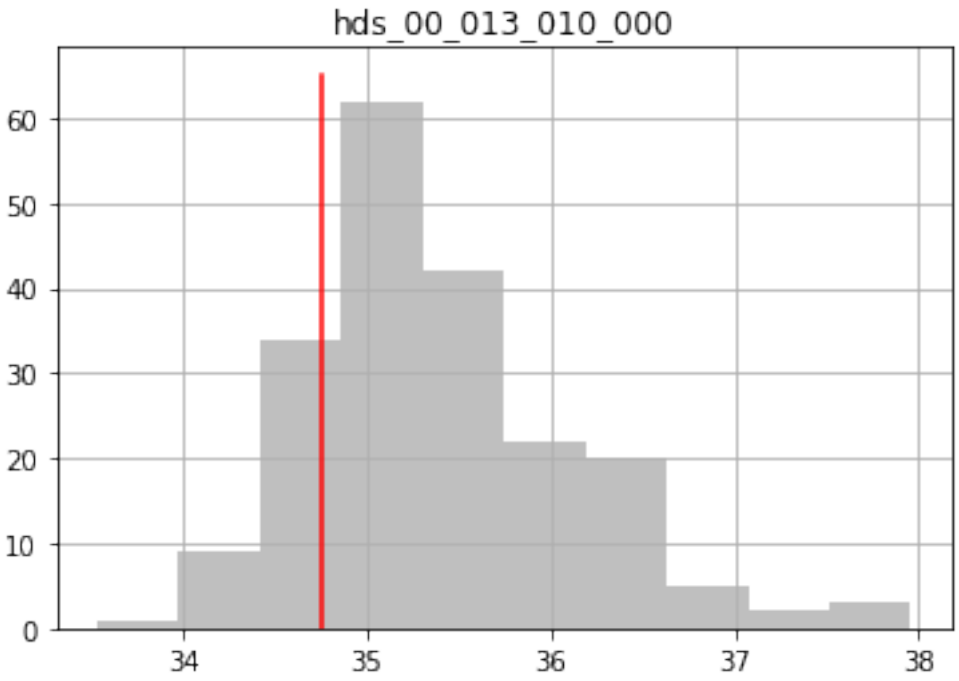


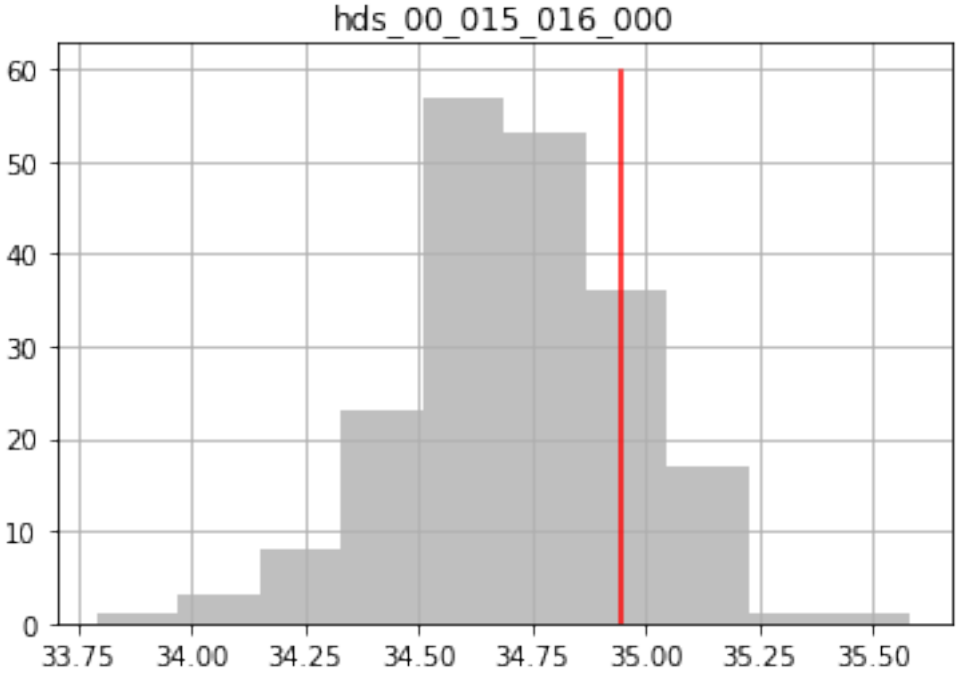

hds_00_002_009_000
60
50
40
30
20
10
0
34
36
38
40
42
44

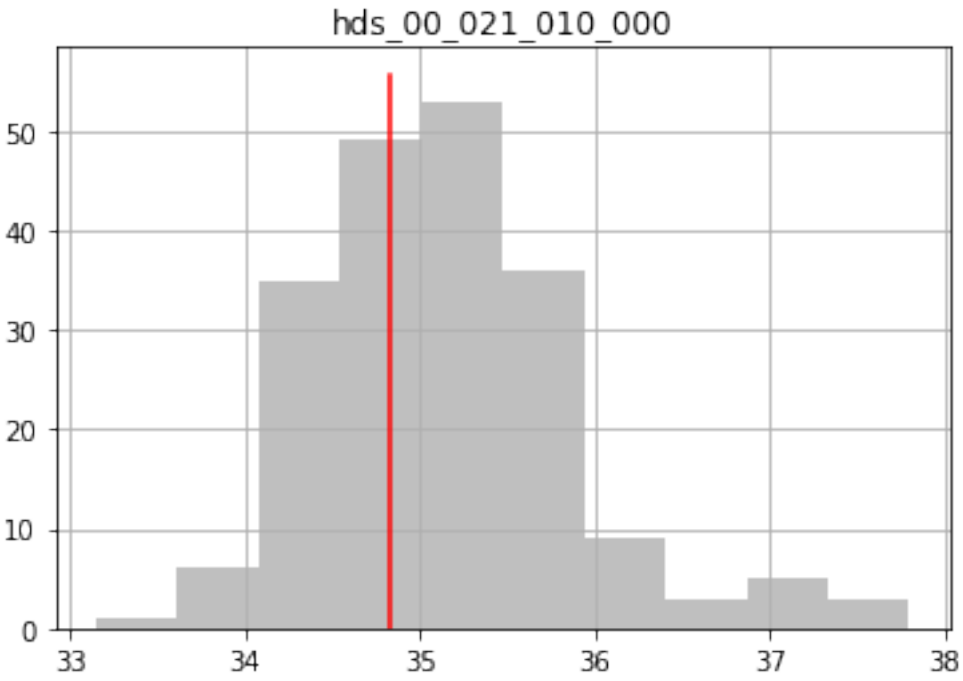

hds_00_002_015_000
70
60
50
40
30
20
10
0
34.5
35.0
35.5
36.0
36.5

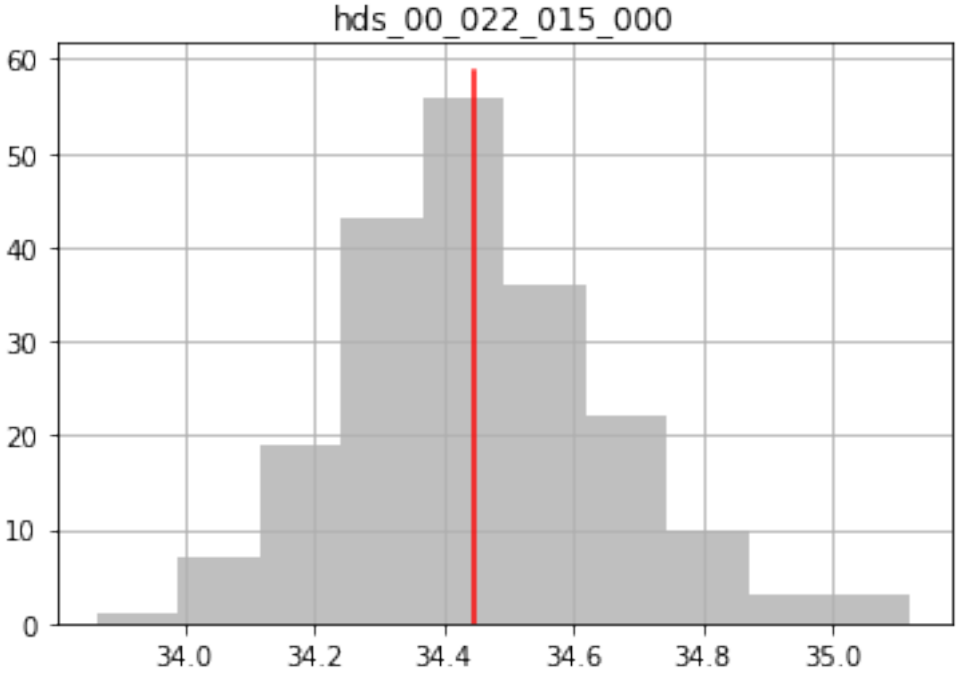

hds_00_003_008_000
60
50
40
30
20
10
0
34
36
38
40
42
44
46

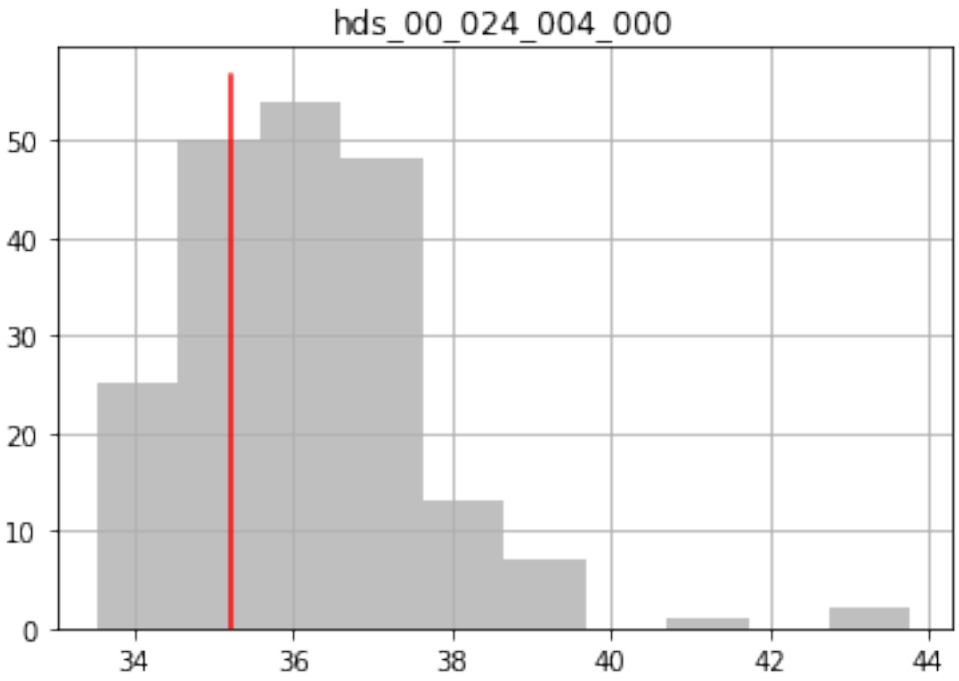

hds_00_009_001_000
50
40
30
20
10
0
35.0
37.5
40.0
42.5
45.0
47.5
50.0

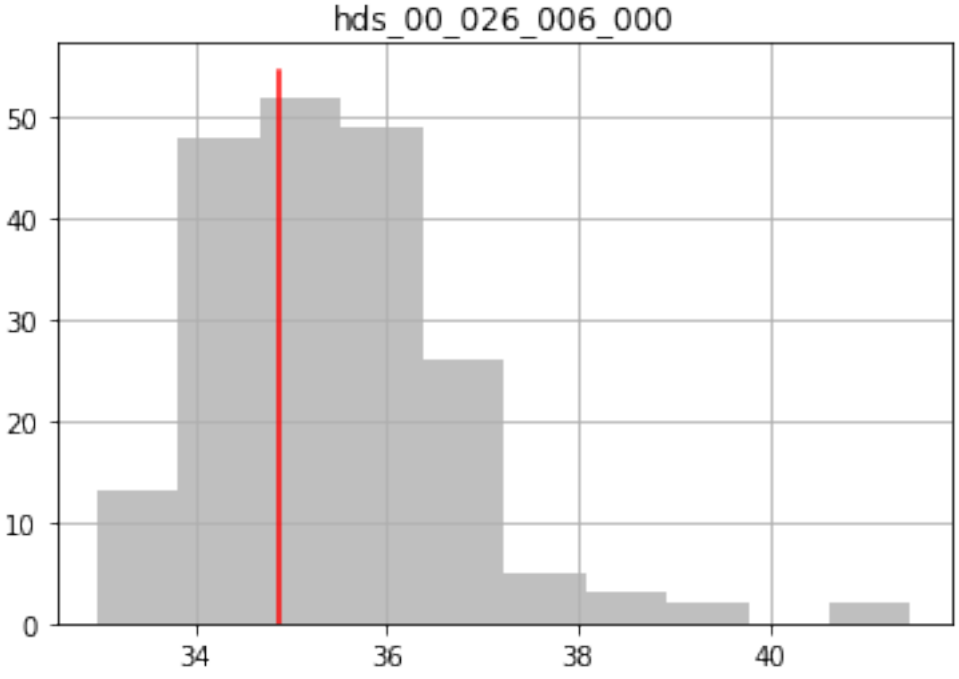

hds_00_013_010_000
60
50
40
30
20
10
0
34
35
36
37
38

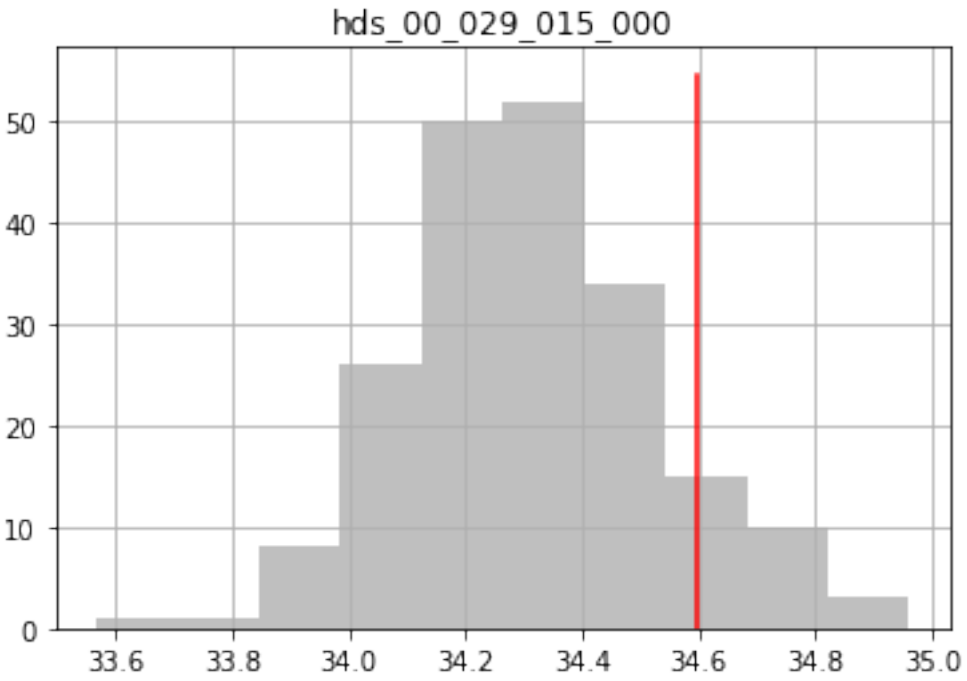

hds_00_015_016_000
60
50
40
30
20
10
0
33.75
34.00
34.25
34.50
34.75
35.00
35.25
35.50

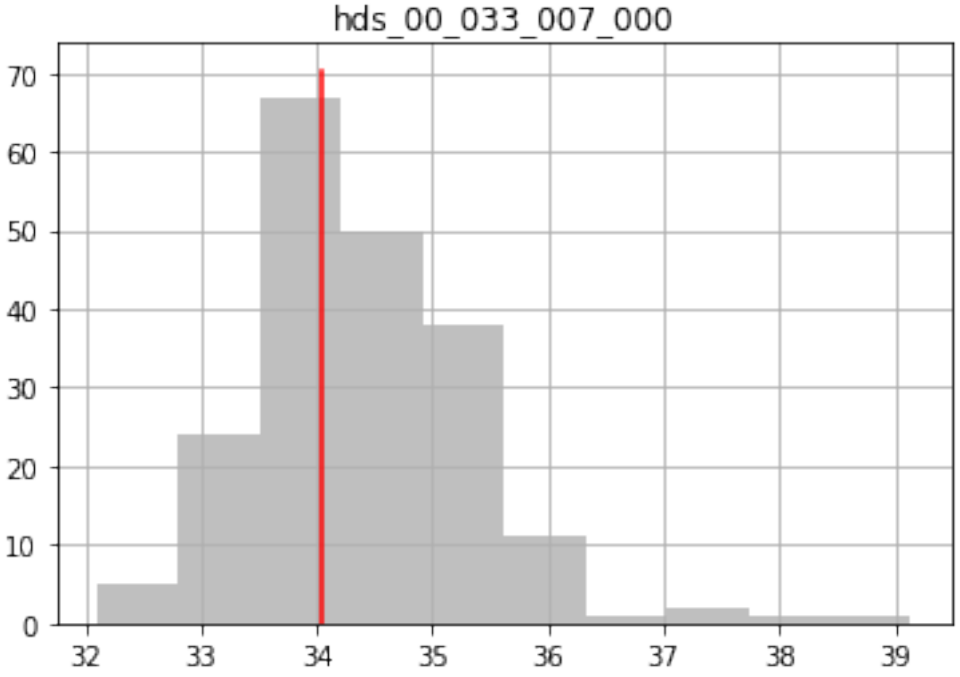

hds_00_021_010_000
0
10
20
30
40
50
33
34
35
36
37
38

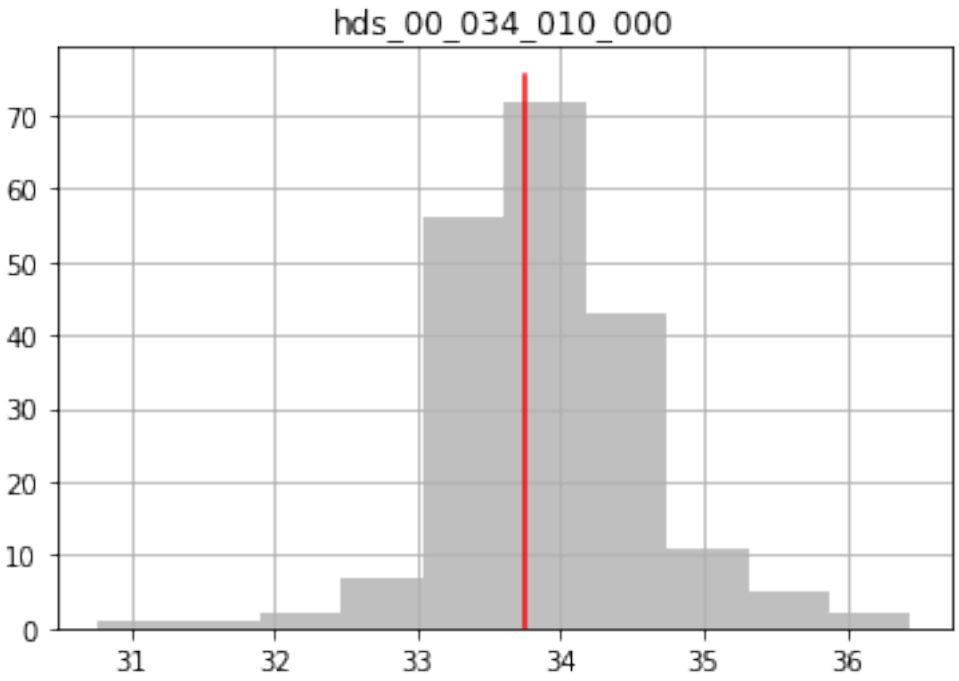

hds_00_022_015_000
0
10
20
30
40
50
60
34.0
34.2
34.4
34.6
34.8
35.0


hds_00_024_004_000
50
40
30
20
10
0
34
36
38
40
42
44


hds_00_026_006_000
50
40
30
20
10
0
34
36
38
40


hds_00_029_015_000
50
40
30
20
10
0
33.6
33.8
34.0
34.2
34.4
34.6
34.8
35.0


hds_00_033_007_000
70
60
50
40
30
20
10
0
32
33
34
35
36
37
38
39


hds_00_034_010_000
70
60
50
40
30
20
10
0
31
32
33
34
35
36