Robust Successive Binarizations (RSB) for Change Detection in Hyperspectral Images

In [1]:

```
#Necessary libraries to be imported:
import numpy as np
import matplotlib.pyplot as plt
import matplotlib.image as mpimg
import time
from os.path import dirname, join as pjoin
from scipy.io import loadmat
from sklearn.metrics import confusion_matrix
import cv2
from sklearn.naive_bayes import GaussianNB
from scipy import stats
```

LOAD the DATASETS

Plase, replace the following `filepath` , `filepathU` , `filepathR` string with your own.

In [2]:

```
filepath = 'C:/Users/antonella/Downloads/ChangeDetectionDataset-master-Hermiston/Change
her1 = pjoin(filepath,'hermiston2004.mat')
her2 = pjoin(filepath,'hermiston2007.mat')
gt = pjoin(filepath,'rdChangesHermiston_5classes.mat')
```

In [3]:

```
filepathU = 'C:/Users/antonella/Downloads/Hyperspectral_Change_Datasets'
usa1 = pjoin(filepathU,'USA1.mat')
usa2 = pjoin(filepathU,'USA2.mat')
gtU = pjoin(filepathU,'USA_gt.mat')
```

In [4]:

```
filepathR = 'C:/Users/antonella/Downloads/GETNET/zuixin'
river1 = pjoin(filepathR,'river_before.mat')
river2 = pjoin(filepathR,'river_after.mat')
gtR = pjoin(filepathR,'groundtruth.mat')
```

In [5]:

```
her1 = loadmat(her1) # Dictionary
her1 = her1['HypeRvieW']
her1 = her1.astype(float)
her2 = loadmat(her2) # Dictionary
her2 = her2['HypeRvieW']
her2 = her2.astype(float)

usa1 = loadmat(usa1)
usa1 = usa1['USA1']
usa1 = usa1.astype(float)
usa2 = loadmat(usa2) # Dictionary
usa2 = usa2['USA2']
usa2 = usa2.astype(float)

river1 = loadmat(river1)
river1 = river1['river_before']
river1 = river1.astype(float)
river2 = loadmat(river2) # Dictionary
river2 = river2['river_after']
river2 = river2.astype(float)
```

In [6]:

```
gt = loadmat(gt)
gt = gt['gt5clasesHermiston']
gt = gt.astype(float)

gtU = loadmat(gtU)
gtU = gtU['USA_gt']
gtU = gtU.astype(float)

gtR = loadmat(gtR)
gtR = gtR['lakelabel_v1']
gtR = gtR.astype(float)
```

In [7]:

```
# Hermiston GT is given for multi-class, hence in order to produce only the binary map
# changed/not-changed pixels, we need to set to 1 all the changed pixels

n2 = np.where(gt.ravel()==2)
n3 = np.where(gt.ravel()==3)
n4 = np.where(gt.ravel()==4)
n5 = np.where(gt.ravel()==5)

new_gt = gt.ravel()
######## &&&& Only for  Hermiston
new_gt[n2] = 1
new_gt[n3] = 1
new_gt[n4] = 1
new_gt[n5] = 1
```

In [8]:

```
[m1,n1,k1] = her1.shape
print('Hermiston dataset size ', m1,n1,k1)

H1 = np.reshape(her1,[m1*n1,k1])
print('Hermiston vectorized ', H1.shape)

[m2,n2,k2] = her2.shape

H2 = np.reshape(her2,[m2*n2,k2])

[mu1,nu1,ku1] = usa1.shape
print('USA dataset size  ', mu1,nu1,ku1)

U1 = np.reshape(usa1,[mu1*nu1,ku1])
print('USA vectorized ', U1.shape)

[mu2,nu2,ku2] = usa2.shape

U2 = np.reshape(usa2,[mu2*nu2,ku2])

[mr1,nr1,kr1] = river1.shape
print('River dataset size  ', mr1,nr1,kr1)

R1 = np.reshape(river1,[mr1*nr1,kr1])
print('River vectorized ', R1.shape)

[mr2,nr2,kr2] = river2.shape

R2 = np.reshape(river2,[mr2*nr2,kr2])
```

```
Hermiston dataset size  390 200 242
Hermiston vectorized  (78000, 242)
USA dataset size   307 241 154
USA vectorized  (73987, 154)
River dataset size   463 241 198
River vectorized  (111583, 198)
```

Error Function Definitions

In [9]:

```
def SAM(x,y):
    norm2_x = np.linalg.norm(x)
    norm2_y = np.linalg.norm(y)
    return np.arccos(np.dot(x,y)/(norm2_x*norm2_y))


def SAM_MEAN(A, B, windowSize=2):
    row, col, feature= A.shape
    C= np.zeros([row, col])
    windSizeMatrix=np.zeros((row, col))

    for i in range(-windowSize, +windowSize+1):
        for j in range(-windowSize, +windowSize+1):
            rowS=max(0,i)
            rowE=min(row,row+i)
            colS=max(0,j)
            colE=min(col,col+j)
            windSizeMatrix[row-rowE:row-rowS, col-colE:col-colS]+=1
            den1= np.sqrt(np.sum(np.multiply(A[rowS:rowE, colS:colE], A[rowS:rowE, colS
            den1[den1 < 1e-5]=1e-5

            den2= np.sqrt(np.sum(np.multiply(B[rowS:rowE, colS:colE], B[rowS:rowE, colS
            den2[den2 < 1e-5]=1e-5
            num=np.sum(np.multiply(A[rowS:rowE, colS:colE],B[rowS:rowE, colS:colE]),axi
            ndiv = np.divide(num, np.multiply(den1,den2))
            ndiv[ndiv > 1] = 1.
            ndiv[ndiv <-1] = -1.
            count=np.arccos(ndiv)

            C[row-rowE:row-rowS, col-colE:col-colS]+=count


    C=np.divide(C, windSizeMatrix).reshape(row,col)

    return C
```

In [10]:

```
def newSSCC(A, B, windowSize=2):

    row, col, feature= A.shape

    nPixel=row*col
    sumA = A.sum(axis=2)
    sumB = B.sum(axis=2)

    BwindowMean=np.zeros(sumB.shape)
    numT=np.zeros(sumA.shape)
    den2T=np.zeros(sumA.shape)
    denT=np.zeros(sumA.shape)

    AwindowMean=np.zeros(sumA.shape)
    windSizeMatrix=np.zeros(sumA.shape)
    den1T=np.zeros(sumA.shape)

    for i in range(-windowSize, +windowSize+1):
        for j in range(-windowSize, +windowSize+1):
                rowS=max(0,i)
                rowE=min(row,row+i)
                colS=max(0,j)
                colE=min(col,col+j)
                AwindowMean[row-rowE:row-rowS, col-colE:col-colS]+=sumA[rowS:rowE, colS

                BwindowMean[row-rowE:row-rowS, col-colE:col-colS]+=sumB[rowS:rowE, colS
                windSizeMatrix[row-rowE:row-rowS, col-colE:col-colS]+=1
        #windSizeMatrix=np.multiply(windSizeMatrix,windSizeMatrix)
        AwindowMean=AwindowMean/(feature)
        #print('\n max AwindowMean ', np.max(AwindowMean))
        BwindowMean=BwindowMean/(feature)
        #print('\n max BwindowMean ', np.max(BwindowMean))
        #print('\n max windSizeMatrix ', np.max(windSizeMatrix))
        BwindowMean=np.divide(BwindowMean, windSizeMatrix)
        AwindowMean=np.divide(AwindowMean, windSizeMatrix)
        #print('\n First division ')

        for i in range(-windowSize, +windowSize+1):
            for j in range(-windowSize, +windowSize+1):
                rowS=max(0,i)
                rowE=min(row,row+i)
                colS=max(0,j)
                colE=min(col,col+j)
                Asubtract=np.zeros(A.shape)
                Bsubtract=np.zeros(A.shape)


                Asubtract[rowS:rowE, colS:colE]=A[rowS:rowE, colS:colE]-AwindowMean[row
                Bsubtract[rowS:rowE, colS:colE]=B[rowS:rowE, colS:colE]-BwindowMean[row

                den1T[row-rowE:row-rowS, col-colE:col-colS]+=np.einsum('ijn,ijn->ij', A

                numT[row-rowE:row-rowS, col-colE:col-colS]+=np.einsum('ijn,ijn->ij', As
                den2T[row-rowE:row-rowS, col-colE:col-colS]+=np.einsum('ijn,ijn->ij', B

        denT=np.multiply(np.sqrt(den1T),np.sqrt(den2T))
        denT[denT< 1e-5]=1e-5
        #print('\n max den1T ', np.max(den1T))
        #print('\n max den2T ', np.max(den2T))
```

```
60          C=1-np.divide(numT,denT).reshape(row, col)
61          #print('\n second division ')
62          return C
63
```

In [11]:

```
def nor01(matrix):
    mi=(matrix.min())
    ma=(matrix).max()
    return (matrix-mi)/(ma-mi)

def Scale(Matrix):
    minMat = np.min(Matrix)
    MaxMat = np.max(Matrix)
    return 1/(MaxMat-minMat+1e-8)*(Matrix-minMat)

def SAM_ZID(A,B):
    row, column, feature= A.shape
    nPixel=row*column
    sam = np.zeros([1,nPixel])
    Ac = A.reshape(nPixel,feature)
    Bc = B.reshape(nPixel,feature)
    for i in range(nPixel):
        sam[0,i] = SAM(Ac[i,:], Bc[i,:])
    diffe = abs(Ac-Bc)
    temp = np.zeros([nPixel, feature])
    for k in range(nPixel):
        temp[k,:] = ((diffe[k,:]-np.mean(diffe[k,:]))/np.std(diffe[k,:]))**2
    zid = np.sum(temp, axis=1)
    sin_angle = nor01( np.sin( sam ))
    zidj = nor01(zid)
    sam_zid= np.prod([[sin_angle[0,:],zidj]], axis=1)

    return sam_zid

def ZID_g_mod(A,B):
    row, column, feature= A.shape
    nPixel=row*column
    A= (A.reshape(nPixel,feature))
    B = B.reshape(nPixel,feature)
    mu_g0=np.zeros([nPixel,1] )
    sigma_g0 = np.zeros([nPixel,1] )
    muB=np.zeros([nPixel,1] )
    sigmaB = np.zeros([nPixel,1] )
    muA=np.zeros([nPixel,1] )
    sigmaA = np.zeros([nPixel,1] )
    C0 =np.copy(abs(A-B)) # modified

    eta = 1e-10
    mu_g0[:,0] = ( (np.sum(np.log(( C0+eta)),axis=1)/A.shape[1]) )

    sigma_g0[:,0] = ( np.sum((( C0+eta-mu_g0)**2), axis=1)/(A.shape[1]) )
    sigma_g0[sigma_g0 < 1e-10]=1e-5

    zid_g = np.sum( (C0-(np.exp(mu_g0)))**2/( ((sigma_g0)) ),axis=1)
    return zid_g

def SAM_g_ZID(A,B):
    row, column, feature= A.shape
    nPixel=row*column
    sam = np.zeros([1,nPixel])
    Ac = A.reshape(nPixel,feature)
    Bc = B.reshape(nPixel,feature)
    for i in range(nPixel):
        sam[0,i] = SAM(Ac[i,:], Bc[i,:])
```

```
    zid =(ZID_g_mod(A,B))
    sin_angle = nor01( np.tan( sam ))
    zidj = nor01(zid)
    sam_zid= np.prod([[sin_angle[0,:],zidj]],axis=1)

    return sam_zid


def OA_K(cnf):
    index = np.nonzero(cnf)
    TN, FP, FN, TP=cnf[index]
    OA = (TP+TN)/(TP+TN+FP+FN)
    p = ((TP + FP)*(TP+FN)+(TN+FN)*(TN+FP))/(TP + TN + FP + FN)**2
    Kappa = (OA-p)/(1-p)
    return OA,Kappa

def Binarize1(M):
    Temp = np.copy(M)
    Temp2 = np.copy(Temp)
    Temp3 = np.copy(Temp)
    Temp4 = np.copy(Temp)
    Temp5 = np.copy(Temp)
    Temp6 = np.copy(Temp)

    Temp2[Temp>=0.2]=1
    Temp2[Temp<0.2]=0

    Temp3[Temp>=0.3]=1
    Temp3[Temp<0.3]=0

    Temp4[Temp>=0.4]=1
    Temp4[Temp<0.4]=0

    Temp5[Temp>=0.5]=1
    Temp5[Temp<0.5]=0

    Temp6[Temp>=0.6]=1
    Temp6[Temp<0.6]=0

    MediaM = (Temp2+Temp3+Temp4+Temp5+ Temp6)/2.0

    return MediaM
```

Euclidean distance

In [12]:

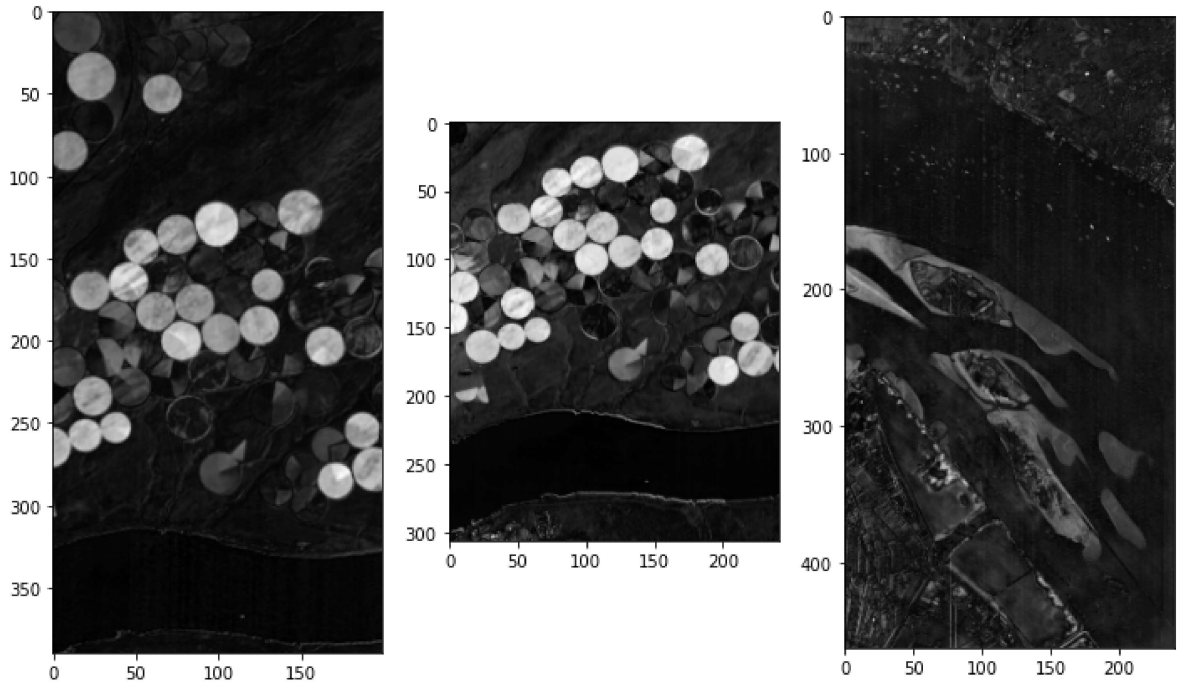
```
diff_matH = H1-H2
EuH = np.zeros([1,m1*n1])
for i in range(m1*n1):
    EuH[0,i] = np.linalg.norm(diff_matH[i,:])


diff_matU = U1-U2
EuU = np.zeros([1,mu1*nu1])
for i in range(mu1*nu1):
    EuU[0,i] = np.linalg.norm(diff_matU[i,:])


diff_matR = R1-R2
EuR = np.zeros([1,mr1*nr1])
for i in range(mr1*nr1):
    EuR[0,i] = np.linalg.norm(diff_matR[i,:])

```

In [14]:

```
fig, (ax1, ax2, ax3) = plt.subplots(1, 3, figsize=(12,9))
fig.suptitle('Euclidean distance')
ax1.imshow(EuH.reshape(m1,n1),cmap = plt.cm.gray)
ax2.imshow(EuU.reshape(mu1,nu1),cmap = plt.cm.gray)
ax3.imshow(EuR.reshape(mr1,nr1),cmap = plt.cm.gray)

```

Out[14]:

```
<matplotlib.image.AxesImage at 0x2581e0fb788>
```



We apply binarization:

- We scale the matrix values between 0 and 1
- We apply several thresholds

In [15]:

```
EuH = Scale(EuH)

EuU = Scale(EuU)

EuR = Scale(EuR)
```

In [16]:

```
MediaEuH = Binarize1(EuH)
MediaEuH[MediaEuH>=1.0]=1.0
MediaEuH[MediaEuH<1.0]=0.0
MediaEuH = MediaEuH.astype(int)

MediaEuU = Binarize1(EuU)
MediaEuU[MediaEuU>=1.0]=1.0
MediaEuU[MediaEuU<1.0]=0.0
MediaEuU = MediaEuU.astype(int)

MediaEuR = Binarize1(EuR)
MediaEuR[MediaEuR>=1.0]=1.0
MediaEuR[MediaEuR<1.0]=0.0
MediaEuR = MediaEuR.astype(int)
```

SAMZID

In [17]:

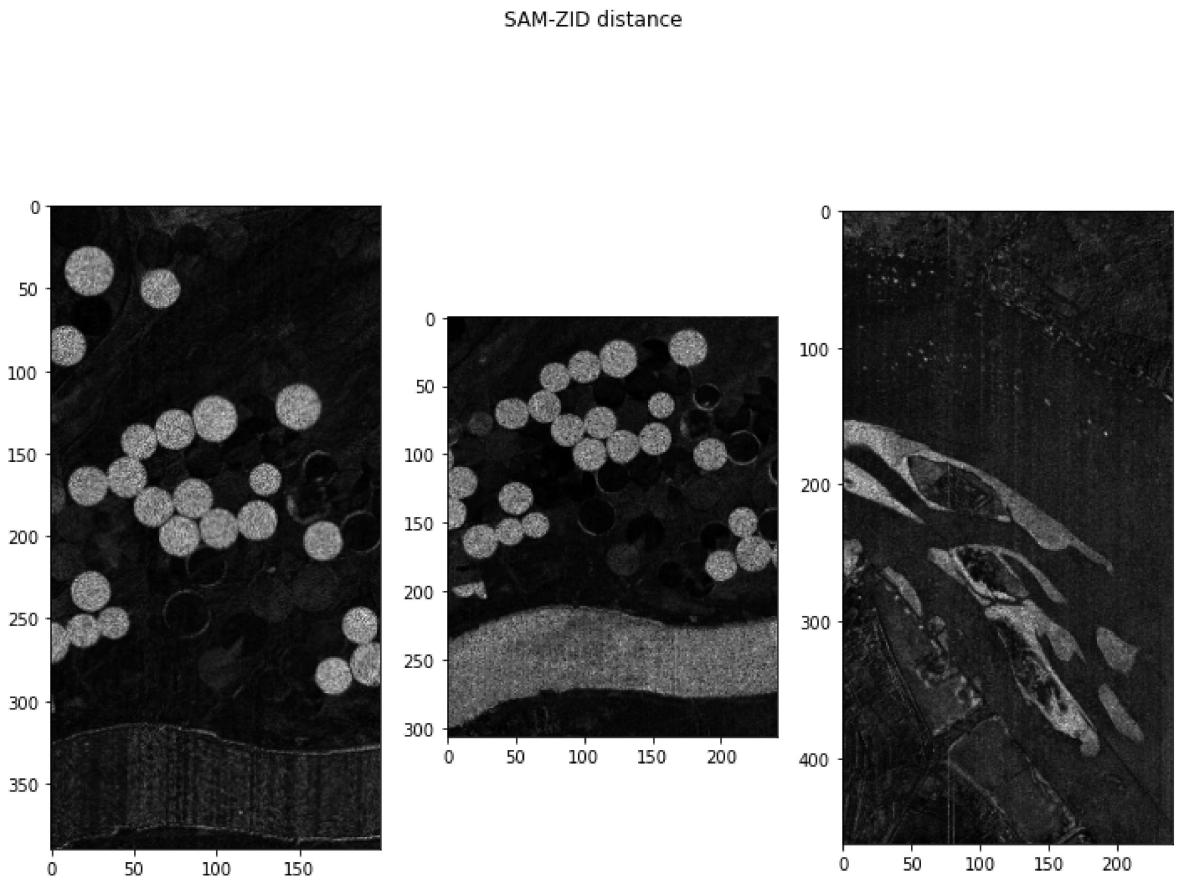
```
Hssz = SAM_ZID(H1.reshape(m1,n1,k1),H2.reshape(m2,n2,k2))

Ussz = SAM_ZID(U1.reshape(mu1,nu1,ku1),U2.reshape(mu2,nu2,ku2))

Rssz = SAM_ZID(R1.reshape(mr1,nr1,kr1),R2.reshape(mr2,nr2,kr2))
```

In [18]:

```
fig, (ax1, ax2, ax3) = plt.subplots(1, 3,figsize=(12,9))
fig.suptitle('SAM-ZID distance')
ax1.imshow(Hssz.reshape(m1,n1),cmap = plt.cm.gray)
ax2.imshow(Ussz.reshape(mu1,nu1), cmap = plt.cm.gray)
ax3.imshow(Rssz.reshape(mr1,nr1), cmap = plt.cm.gray)
```

Out[18]:

```
<matplotlib.image.AxesImage at 0x2581de16dc8>
```



In [19]:

```
Hssz = Scale(Hssz)

Ussz = Scale(Ussz)

Rssz = Scale(Rssz)
```

In [20]:

```
MediaHssz = Binarize1(Hssz)
MediaHssz[MediaHssz>=1.0]=1.0
MediaHssz[MediaHssz<1.0]=0.0
MediaHssz = MediaHssz.astype(int)


MediaUssz =  Binarize1(Ussz)
MediaUssz[MediaUssz>=1.0]=1.0
MediaUssz[MediaUssz<1.0]=0.0
MediaUssz = MediaUssz.astype(int)


MediaRssz =  Binarize1(Rssz)
MediaRssz[MediaRssz>=1.0]=1.0
MediaRssz[MediaRssz<1.0]=0.0
MediaRssz= MediaRssz.astype(int)
```

SAM-MEAN

In [21]:

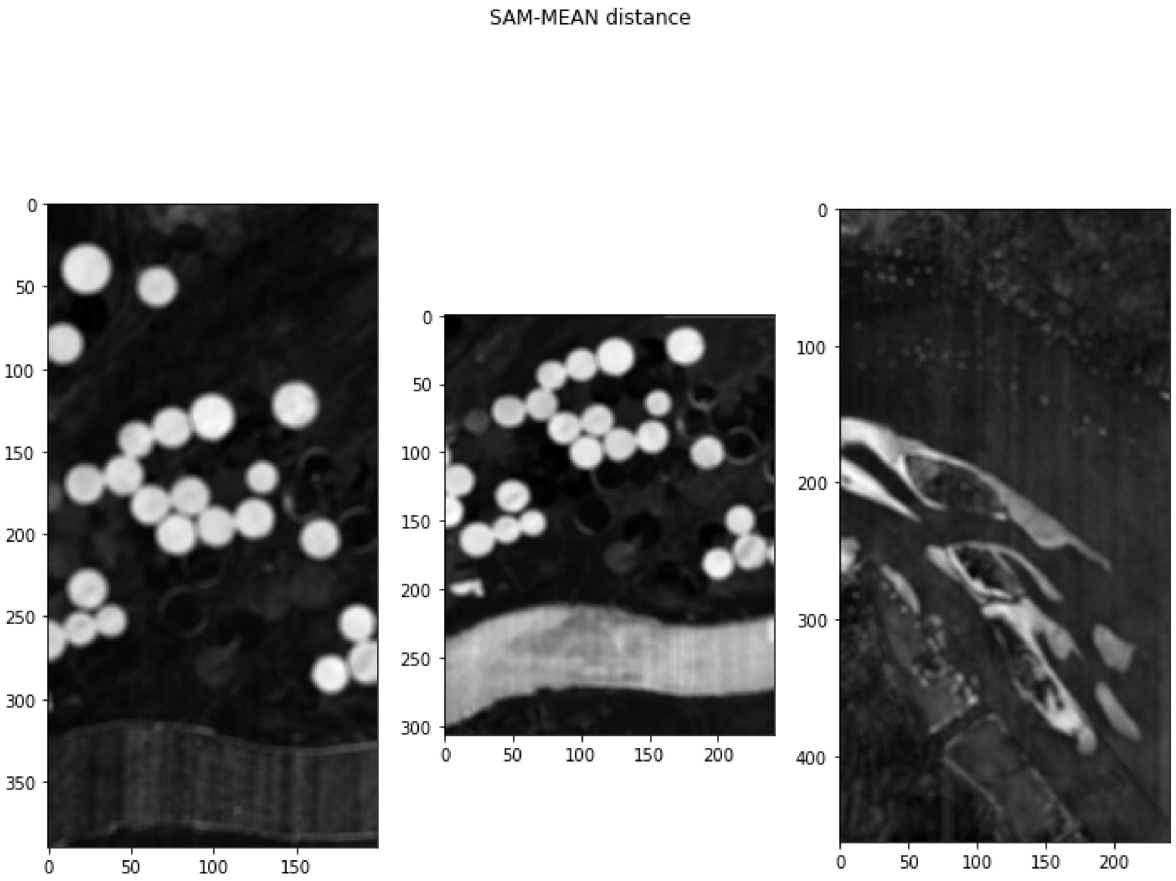
```
HsM = SAM_MEAN(H1.reshape(m1,n1,k1), H2.reshape(m2,n2,k2))

UsM = SAM_MEAN(U1.reshape(mu1,nu1,ku1), U2.reshape(mu2,nu2,ku2))

RsM = SAM_MEAN(R1.reshape(mr1,nr1,kr1), R2.reshape(mr2,nr2,kr2))
```

In [23]:

```
fig, (ax1, ax2, ax3) = plt.subplots(1, 3,figsize=(12,9))
fig.suptitle('SAM-MEAN distance')
ax1.imshow(HsM,cmap = plt.cm.gray)
ax2.imshow(UsM, cmap = plt.cm.gray)
ax3.imshow(RsM, cmap = plt.cm.gray)
```

Out[23]:

```
<matplotlib.image.AxesImage at 0x258264b2e48>
```



In [24]:

```
HsM = Scale(HsM)

UsM = Scale(UsM)

RsM = Scale(RsM)
```

In [25]:

```
MediaHsM =  Binarize1(HsM)
MediaHsM[MediaHsM>=1.0]=1.0
MediaHsM[MediaHsM<1.0]=0.0
MediaHsM = MediaHsM.astype(int)


MediaUsM =  Binarize1(UsM)
MediaUsM[MediaUsM>=1.0]=1.0
MediaUsM[MediaUsM<1.0]=0.0
MediaUsM = MediaUsM.astype(int)


MediaRsM =  Binarize1(RsM)
MediaRsM[MediaRsM>=1.0]=1.0
MediaRsM[MediaRsM<1.0]=0.0
MediaRsM = MediaRsM.astype(int)
```

In [26]:

```
'''To uncomment only if chunks of codes are run not in the prescribed order, as  dimens

#[m1,n1,k1] = her1.shape

#H1 = np.reshape(her1,[m1*n1,k1])

#[m2,n2,k2] = her2.shape

#H2 = np.reshape(her2,[m2*n2,k2])
```

Out[26]:

```
'To uncomment only if chunks of codes are run not in the prescribed order, a
s  dimensions might be different'
```

SMSADM

In [27]:

```
Hsc = newSSCC(H1.reshape(m1,n1,k1), H2.reshape(m2,n2,k2))

Usc = newSSCC(U1.reshape(mu1,nu1,ku1), U2.reshape(mu2,nu2,ku2))

Rsc = newSSCC(R1.reshape(mr1,nr1,kr1), R2.reshape(mr2,nr2,kr2))
```

...

In [28]:

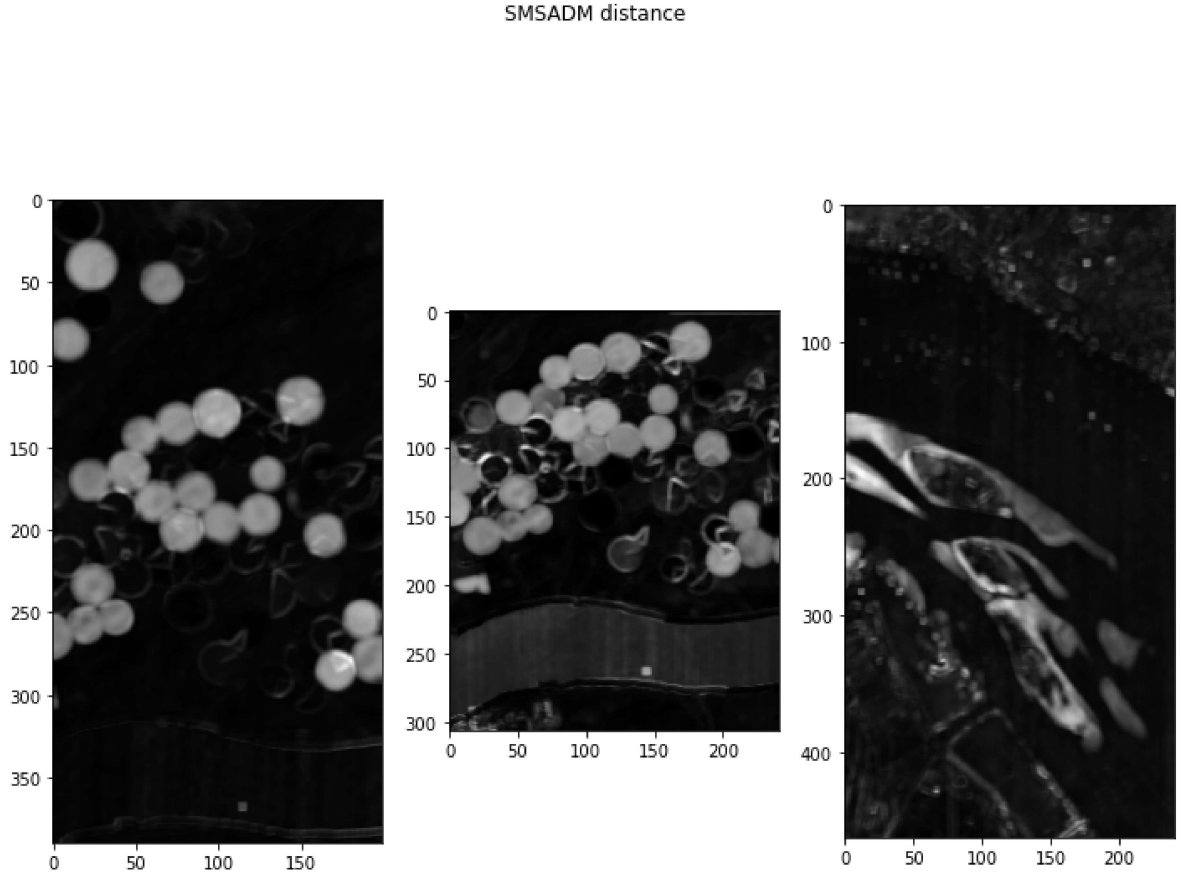
```
# The images are not preprocessed, SMSADM might produces some sporious "0/0"
Hsc[np.isnan(Hsc)]=0

Usc[np.isnan(Usc)]=0

Rsc[np.isnan(Rsc)]=0

```

In [30]:

```
fig, (ax1, ax2, ax3) = plt.subplots(1, 3, figsize=(12,9))
fig.suptitle('SMSADM distance')
ax1.imshow(Hsc.reshape(m1,n1),cmap = plt.cm.gray)
ax2.imshow(Usc.reshape(mu1,nu1), cmap = plt.cm.gray)
ax3.imshow(Rsc.reshape(mr1,nr1), cmap = plt.cm.gray)
```

Out[30]:

```
<matplotlib.image.AxesImage at 0x25826a0a348>
```



In [31]:

```
Hsc = Scale(Hsc)

Usc = Scale(Usc)

Rsc = Scale(Rsc)
```

In [32]:

```
MediaHsc = Binarize1(Hsc)
MediaHsc[MediaHsc>=1.0]=1.0
MediaHsc[MediaHsc<1.0]=0.0
MediaHsc = MediaHsc.astype(int)

MediaUsc =  Binarize1(Usc)
MediaUsc[MediaUsc>=1.0]=1.0
MediaUsc[MediaUsc<1.0]=0.0
MediaUsc = MediaUsc.astype(int)


MediaRsc =  Binarize1(Rsc)
MediaRsc[MediaRsc>=1.0]=1.0
MediaRsc[MediaRsc<1.0]=0.0
MediaRsc = MediaRsc.astype(int)
```

$\| \cdot \|_1$

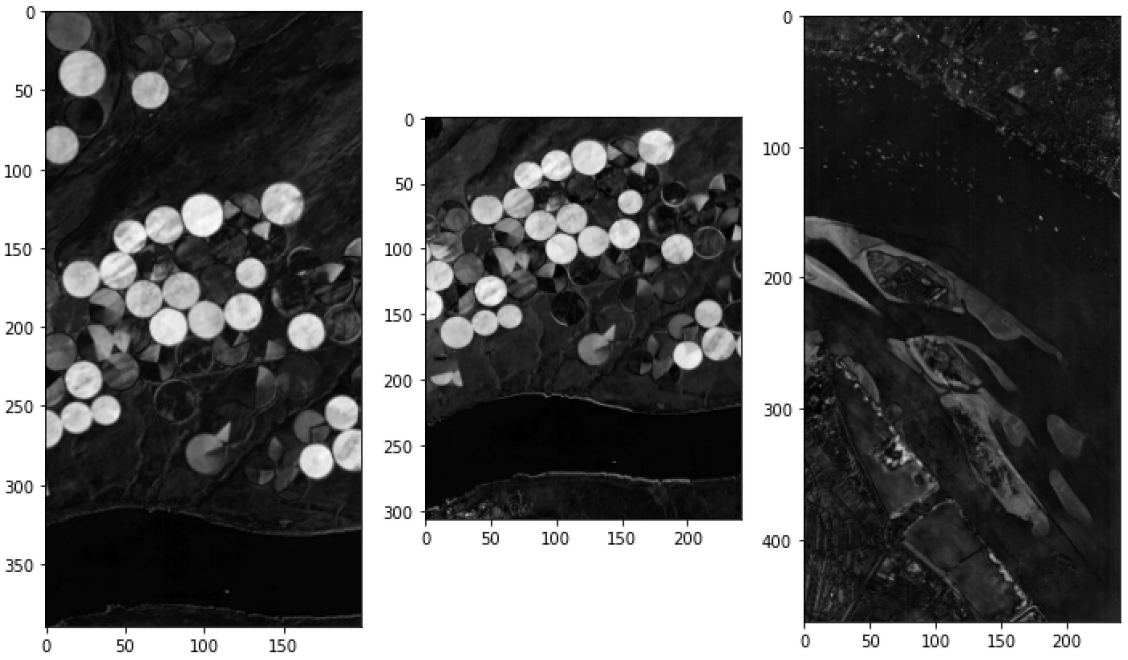
In [34]:

```
H1norm = np.zeros(m1*n1)
U1norm = np.zeros(mu1*nu1)
R1norm = np.zeros(mr1*nr1)

for i in range(m1*n1):
    H1norm[i]= np.sum(abs(H1[i,:]-H2[i,:]))
for i in range(mu1*nu1):
    U1norm[i]= np.sum(abs(U1[i,:]-U2[i,:]))
for i in range(mr1*nr1):
    R1norm[i]= np.sum(abs(R1[i,:]-R2[i,:]))


fig, (ax1, ax2, ax3) = plt.subplots(1, 3, figsize=(12,9))
fig.suptitle('1-norm')
ax1.imshow(H1norm.reshape(m1,n1),cmap = plt.cm.gray)
ax2.imshow(U1norm.reshape(mu1,nu1), cmap = plt.cm.gray)
ax3.imshow(R1norm.reshape(mr1,nr1), cmap = plt.cm.gray)


H1norm = Scale(H1norm)
U1norm = Scale(U1norm)
R1norm = Scale(R1norm)


MediaH1norm = Binarize1(H1norm)
MediaH1norm[MediaH1norm>=1.0]=1.0
MediaH1norm[MediaH1norm<1.0]=0.0
MediaH1norm = MediaH1norm.astype(int)


MediaU1norm =  Binarize1(U1norm)
MediaU1norm[MediaU1norm>=1.0]=1.0
MediaU1norm[MediaU1norm<1.0]=0.0
MediaU1norm = MediaU1norm.astype(int)


MediaR1norm =  Binarize1(R1norm)
MediaR1norm[MediaR1norm>=1.0]=1.0
MediaR1norm[MediaR1norm<1.0]=0.0
MediaR1norm = MediaR1norm.astype(int)

#####

fig, (ax1, ax2, ax3) = plt.subplots(1, 3, figsize=(12,9))
fig.suptitle('Media 1-norm')
ax1.imshow(MediaH1norm.reshape(m1,n1),cmap = plt.cm.gray)
ax2.imshow(MediaU1norm.reshape(mu1,nu1), cmap = plt.cm.gray)
ax3.imshow(MediaR1norm.reshape(mr1,nr1), cmap = plt.cm.gray)
```

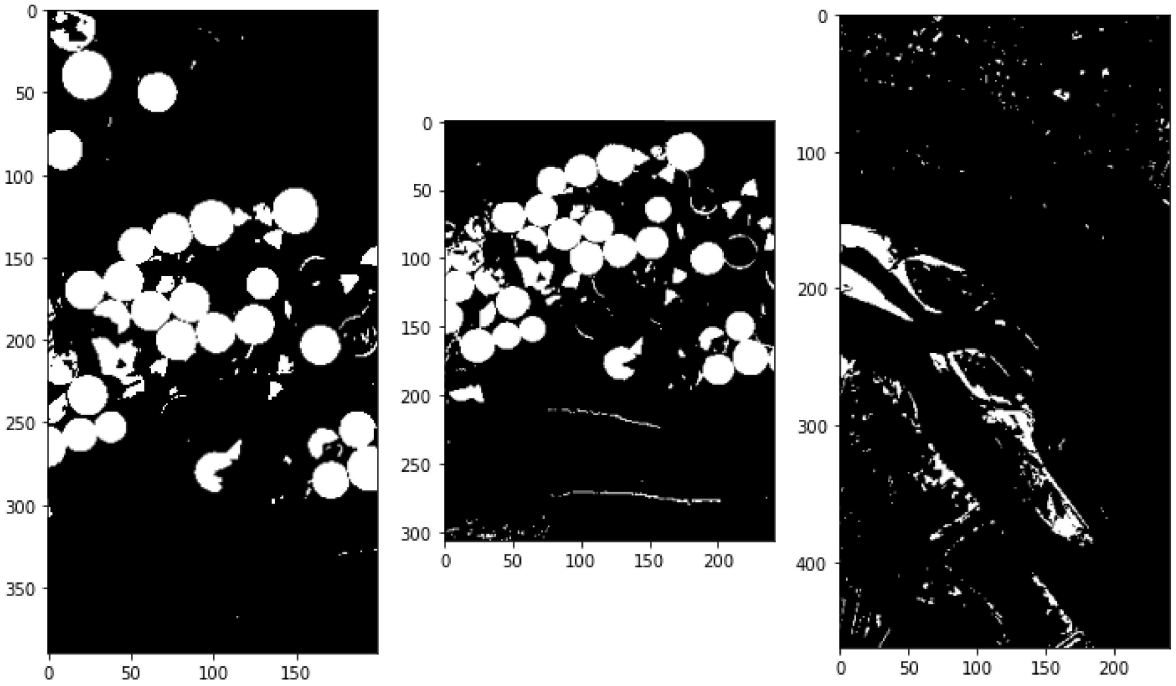
Out[34]:

```
<matplotlib.image.AxesImage at 0x2581e328448>
```

1-norm



Media 1-norm

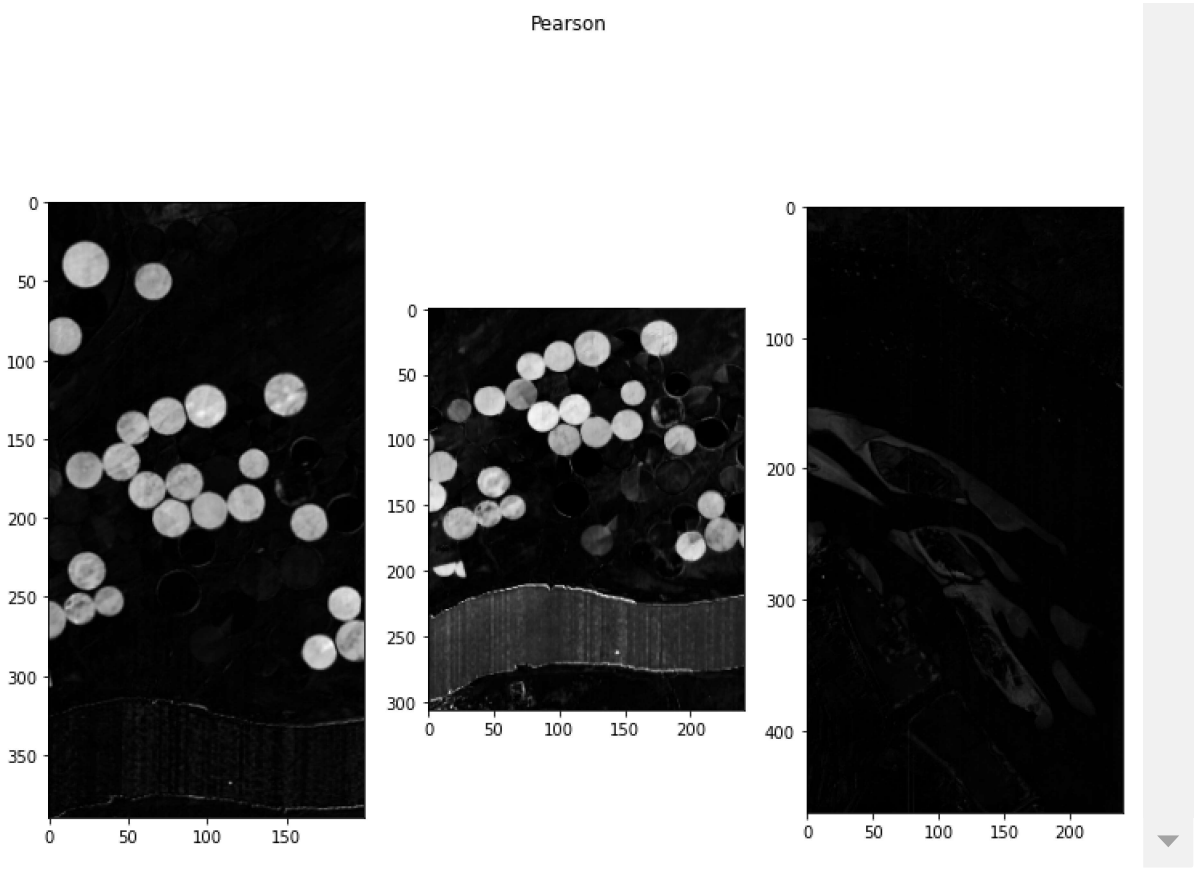


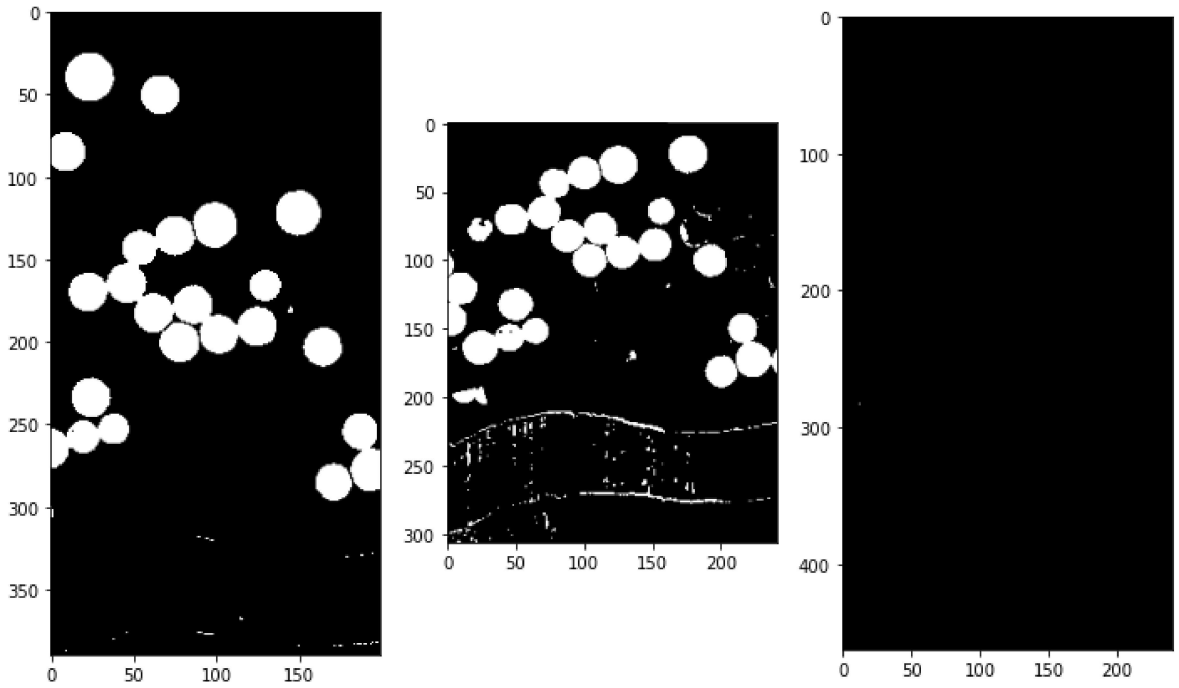
In [36]:

```
Hpr = np.zeros(m1*n1)
Upr = np.zeros(mu1*nu1)
Rpr = np.zeros(mr1*nr1)

for i in range(m1*n1):
    Hpr[i],sH = stats.pearsonr((H1[i,:]),(H2[i,:]))
for i in range(mu1*nu1):
    Upr[i],sU = stats.pearsonr((U1[i,:]),(U2[i,:]))
for i in range(mr1*nr1):
    Rpr[i],sR = stats.pearsonr((R1[i,:]),(R2[i,:]))


Hpr = 1-abs(Hpr)
Upr = 1-abs(Upr)
Rpr = 1-abs(Rpr)


fig, (ax1, ax2, ax3) = plt.subplots(1, 3, figsize=(12,9))
fig.suptitle('Pearson')
ax1.imshow(Hpr.reshape(m1,n1),cmap = plt.cm.gray)
ax2.imshow(Upr.reshape(mu1,nu1), cmap = plt.cm.gray)
ax3.imshow(Rpr.reshape(mr1,nr1), cmap = plt.cm.gray)


Hpr = Scale(Hpr)
Upr = Scale(Upr)
Rpr = Scale(Rpr)


MediaHpr = Binarize1(Hpr)
MediaHpr[MediaHpr>=1.0]=1.0
MediaHpr[MediaHpr<1.0]=0.0
MediaHpr = MediaHpr.astype(int)


MediaUpr =  Binarize1(Upr)
MediaUpr[MediaUpr>=1.0]=1.0
MediaUpr[MediaUpr<1.0]=0.0
MediaUpr = MediaUpr.astype(int)


MediaRpr =  Binarize1(Rpr)
MediaRpr[MediaRpr>=1.0]=1.0
MediaRpr[MediaRpr<1.0]=0.0
MediaRpr = MediaRpr.astype(int)

#####

fig, (ax1, ax2, ax3) = plt.subplots(1, 3, figsize=(12,9))
fig.suptitle('Media Pearson')
ax1.imshow(MediaHpr.reshape(m1,n1),cmap = plt.cm.gray)
ax2.imshow(MediaUpr.reshape(mu1,nu1), cmap = plt.cm.gray)
ax3.imshow(MediaRpr.reshape(mr1,nr1), cmap = plt.cm.gray)
```

Out[36]:

```
<matplotlib.image.AxesImage at 0x258272f8088>
```





In [37]:

```
HsM+MediaHpr.reshape(m1,n1)+MediaH1norm.reshape(m1,n1)+MediaHssz.reshape(m1,n1))#
diaUsc+MediaUpr.reshape(mu1,nu1)+MediaU1norm.reshape(mu1,nu1)+MediaUssz.reshape(mu1,nu1))#
diaRsM+MediaRpr.reshape(mr1,nr1)+MediaR1norm.reshape(mr1,nr1)+MediaRssz.reshape(mr1,nr1))#
```

In [38]:

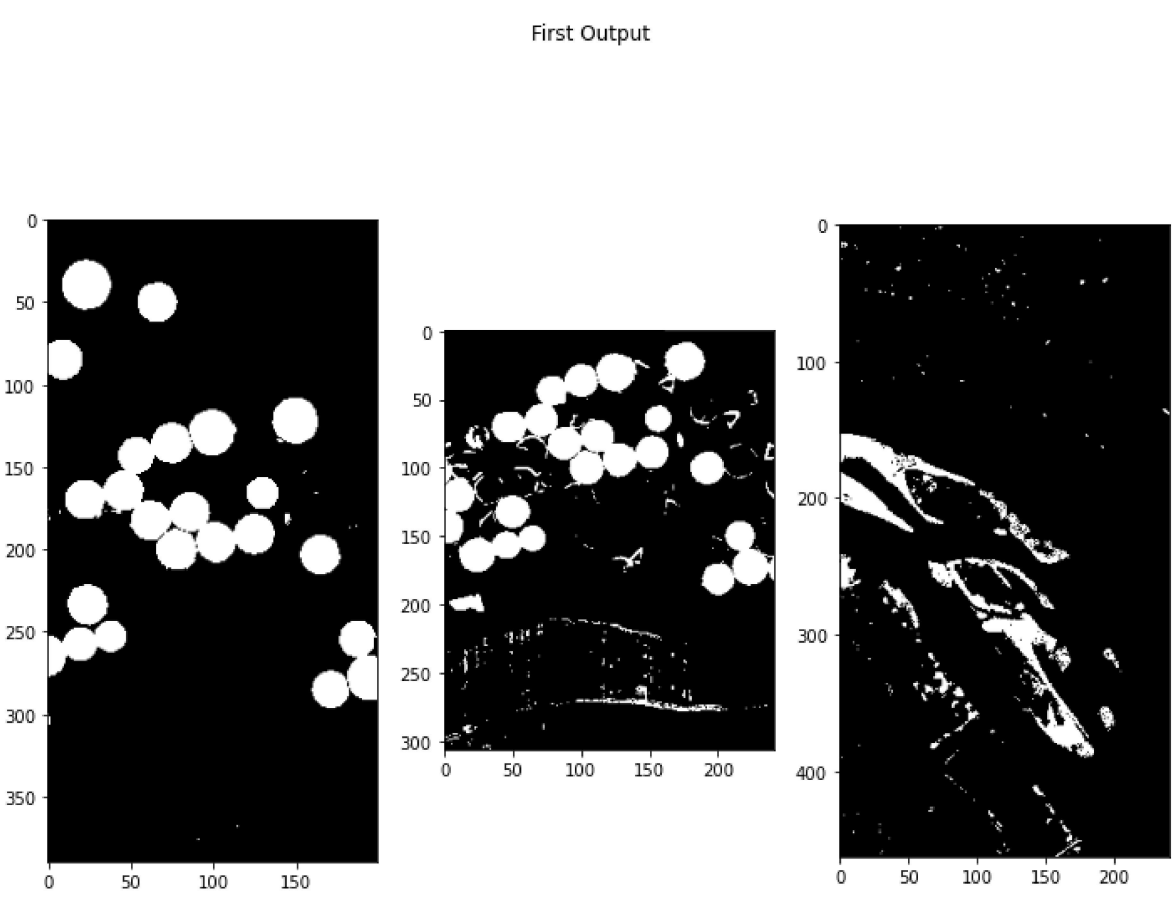
```
nOUT_H = np.copy(OUT_H)
nOUT_H[nOUT_H<3]=0
nOUT_H[nOUT_H>=3]=1


nOUT_U = np.copy(OUT_U)
nOUT_U[nOUT_U<3]=0
nOUT_U[nOUT_U>=3]=1


nOUT_R = np.copy(OUT_R)
nOUT_R[nOUT_R<3]=0
nOUT_R[nOUT_R>=3]=1
```

In [39]:

```
fig, (ax1, ax2, ax3) = plt.subplots(1, 3, figsize=(12,9))
fig.suptitle('First Output')
ax1.imshow(nOUT_H.reshape(m1,n1),cmap = plt.cm.gray)
ax2.imshow(nOUT_U.reshape(mu1,nu1), cmap = plt.cm.gray)
ax3.imshow(nOUT_R.reshape(mr1,nr1), cmap = plt.cm.gray)
```

Out[39]:

```
<matplotlib.image.AxesImage at 0x258266fc2c8>
```



In [40]:

```
cnfH =confusion_matrix(new_gt, nOUT_H.ravel()).ravel()
OAH,KH = OA_K(cnfH)
print('\n overall accuracy Hermiston  ', OAH)
print('\n Kappa coeff Hermiston  ', KH)


cnfU =confusion_matrix(gtU.ravel(), nOUT_U.ravel()).ravel()
OAU,KU = OA_K(cnfU)
print('\n overall accuracy USA  ', OAU)
print('\n Kappa coeff USA  ', KU)


cnfR =confusion_matrix(gtR.ravel(), nOUT_R.ravel()).ravel()
OAR,KR = OA_K(cnfR)
print('\n overall accuracy River  ', OAR)
print('\n Kappa coeff River  ', KR)

```

```
overall accuracy Hermiston   0.9866794871794872

Kappa coeff Hermiston   0.9410218110311578

overall accuracy USA   0.9108221714625543

Kappa coeff USA   0.7164311235731688

overall accuracy River   0.9624405151322334

Kappa coeff River   0.7250442980210057
```

Post-Processing Step:

- For 'Usa' and 'River' dataset, the obtained results can be improved by using the current output as pseudo-labels to a supervised binary classifier
- For 'Hermiston' dataset, since the produced output is a very neat binary map, it is convenient to adopt a pixel-wise cleaning/noise-removal method.

Difference images:

In [41]:

```
imgU = abs(U1-U2)
imgR = abs(R1-R2)
```

1st iteration Gaussian NB

In [42]:

```
clfU = GaussianNB()
outUF = clfU.fit(imgU, nOUT_U.reshape(mu1*nu1)).predict(imgU)

clfR = GaussianNB()
outRF = clfR.fit(imgR, nOUT_R.reshape(mr1*nr1)).predict(imgR)


cnfU =confusion_matrix(gtU.ravel(), outUF).ravel()
OAU,KU = OA_K(cnfU)
print('\n overall accuracy USA  ', OAU)
print('\n Kappa coeff USA  ', KU)


cnfR =confusion_matrix(gtR.ravel(), outRF).ravel()
OAR,KR = OA_K(cnfR)
print('\n overall accuracy River  ', OAR)
print('\n Kappa coeff River  ', KR)

```

```
 overall accuracy USA   0.9451390109073216

 Kappa coeff USA   0.8341752117302464

 overall accuracy River   0.9609438713782565

 Kappa coeff River   0.7711179927663249
```

2nd iteration of Gaussian Nb

In [43]:

```
clfU = GaussianNB(var_smoothing=.11252e-2)#
outUF = clfU.fit(imgU, outUF.reshape(mu1*nu1)).predict(imgU)
clfR = GaussianNB(var_smoothing=1.0)
outRF = clfR.fit(imgR, outRF.reshape(mr1*nr1)).predict(imgR)


cnfU =confusion_matrix(gtU.ravel(), outUF).ravel()
OAU,KU = OA_K(cnfU)
print('\n overall accuracy USA  ', OAU)
print('\n Kappa coeff USA  ', KU)


cnfR =confusion_matrix(gtR.ravel(), outRF).ravel()
OAR,KR = OA_K(cnfR)
print('\n overall accuracy River  ', OAR)
print('\n Kappa coeff River  ', KR)
```

```
 overall accuracy USA   0.9528025193615095

 Kappa coeff USA   0.8630043054922464

 overall accuracy River   0.9681223842341575

 Kappa coeff River   0.8013886129992429
```

For the Hermiston dataset instead it is convenient to remove the noise by adopting a pixel wise "filter". For such aim, a morphological opening transformation is chosen.

In [44]:

```
def clean_map1(change_map):
    change_map = change_map.astype(np.uint8)
    kernel1     = np.asarray(( 0,0,1,0,0),
                             (0,1,1,1,0),
                             (1,1,1,1,1),
                             (0,1,1,1,0),
                             (0,0,1,0,0)), dtype=np.uint8)

    cleanChangeMap = cv2.morphologyEx(change_map, cv2.MORPH_OPEN, kernel1)

    return cleanChangeMap
```

In [45]:

```
CleanedH = clean_map1(nOUT_H.reshape(m1,n1))
```

In [46]:

```
cnfH =confusion_matrix(new_gt, CleanedH.ravel()).ravel()
OAH,KH = OA_K(cnfH)
print('\n overall accuracy Hermiston  ', OAH)
print('\n Kappa coeff Hermiston  ', KH)
```

```
 overall accuracy Hermiston   0.9875512820512821

 Kappa coeff Hermiston   0.9446715027943061
```

In [47]:

```
fig, (ax1, ax2, ax3) = plt.subplots(1, 3,figsize=(12,9))
ax1.imshow(CleanedH.reshape(m1,n1),cmap = plt.cm.gray)
ax2.imshow(outUF.reshape(mu1,nu1), cmap = plt.cm.gray)
ax3.imshow(outRF.reshape(mr1,nr1), cmap = plt.cm.gray)
plt.title('Final Output')

```

Out[47]:

```
Text(0.5, 1.0, 'Final Output')
```