International Conference and Exhibition on
Satellite
August 17-19, 2015 Houston, Texas, USA

Current Land Subsidence in the Houston Metropolitan Area, Texas, Derived from GPS Observations (1993-2012)

NCALM
The National Center for Airborne Laser Mapping
University of Houston • University of California, Berkeley

Guoquan (Bob) Wang

August 17, 2015

With contributions from graduate students: Timothy J. Kearns, Jiangbo Yu, Linqiang Yang, Hanlin Liu, Xueyi Jia, and Jianjun Jiang

Outline

- GPS Geodesy Infrastructure in the Houston area

  Public available GPS stations (Hardware)

  Stable Houston Reference Frame (SHRF) (Firmware)

  Single-receiver phase ambiguity resolved GIPSY PPP resolution (software)

- Current subsidence mapping (2005-2012)

- Scientific Questions:

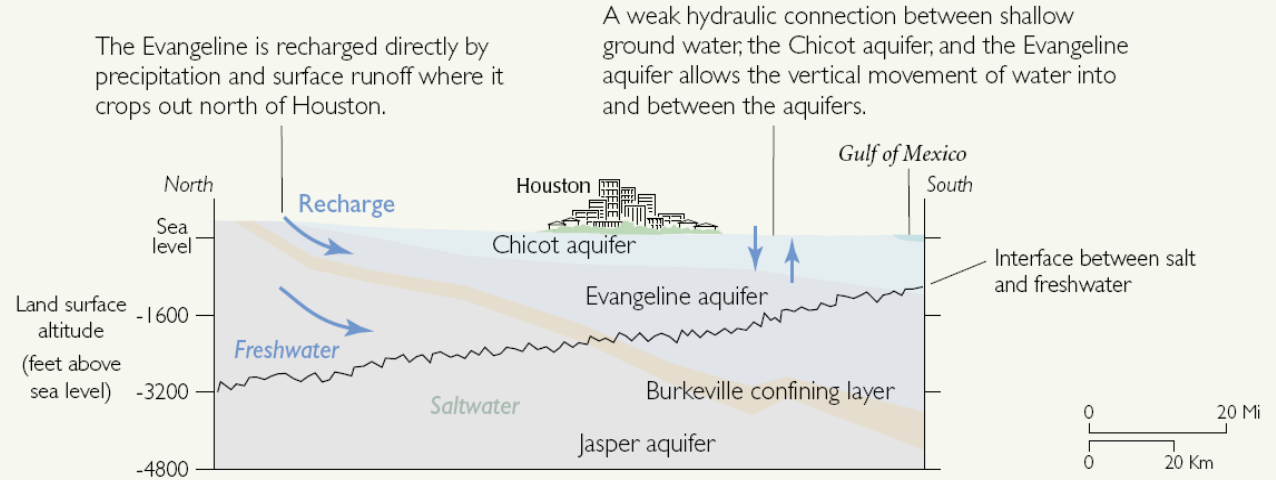
  (1) Is there deep seated (or fault-controlled) subsidence in the Houston area?

  (2) When will the current subsidence stop?

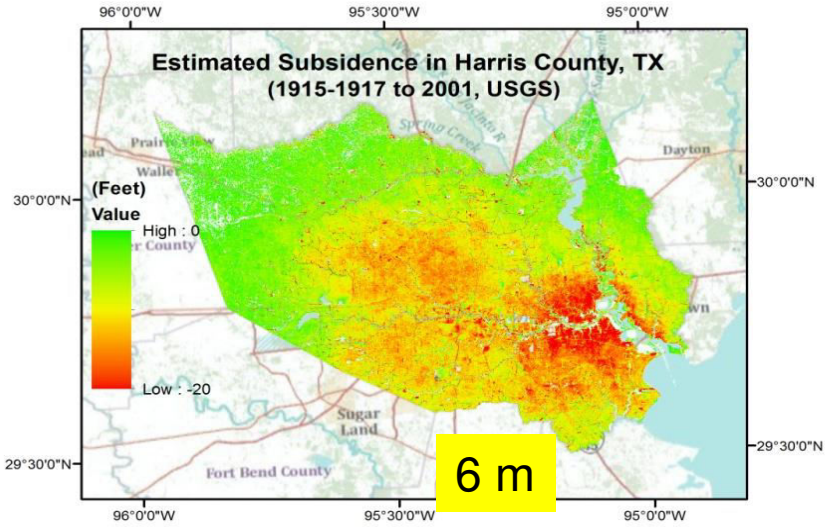
USGS
science for a changing world

HARRIS - GALVESTON SUBSIDENCE DISTRICT

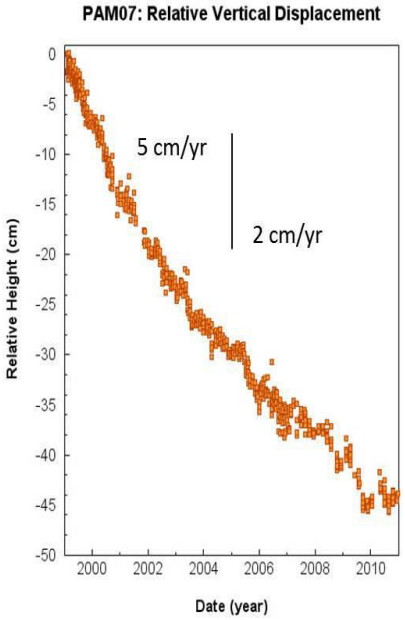
THE Subsidence DISTRICTS

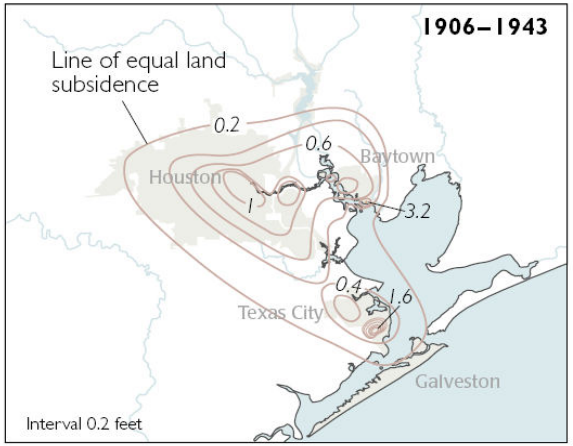


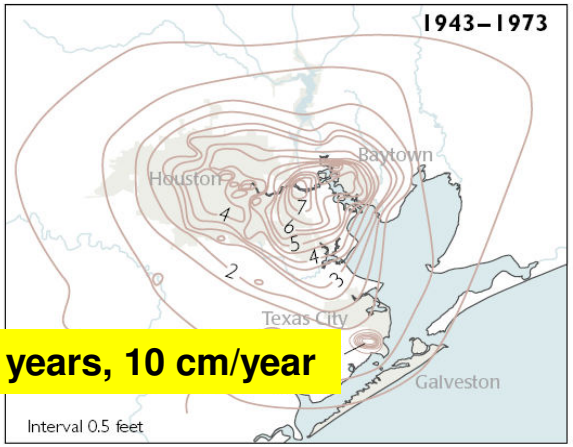
(USGS, Coplin and Galloway, 2009)



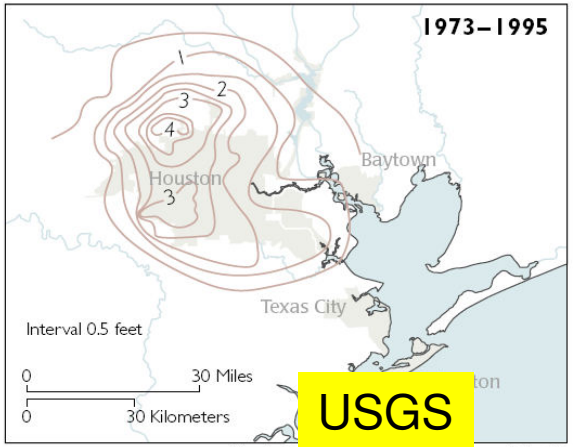
(USGS, Kasmarek et al., 2009)







) years, 10 cm/year



USGS

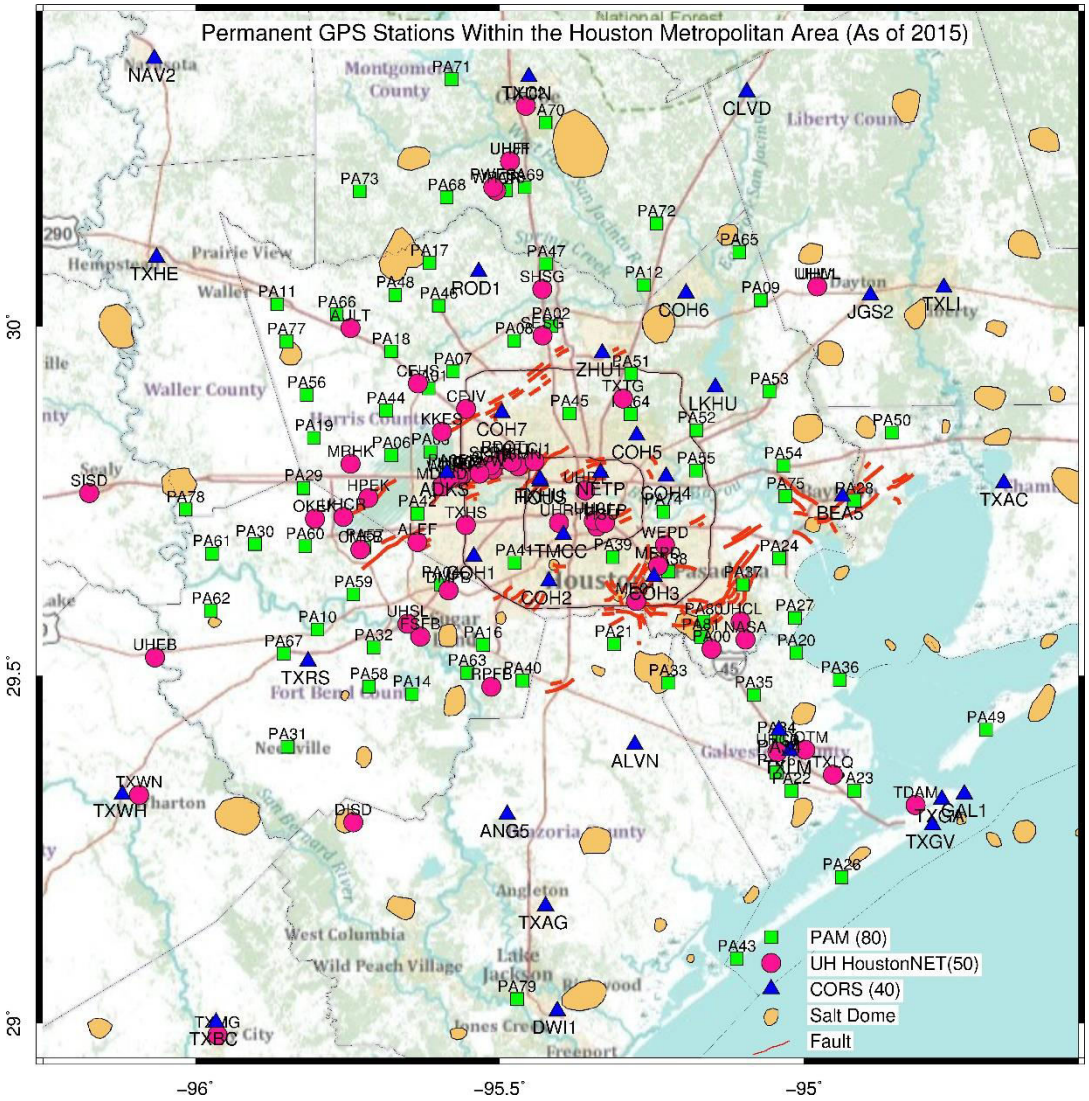
(Harris-Galveston Coastal Subsidence District)

Historic Subsidence in Houston

Houston Ship Channel Area

$ 42.23/Barrel
August 14, 2015

Geodesy Infrastructure: Permanent GPS Stations



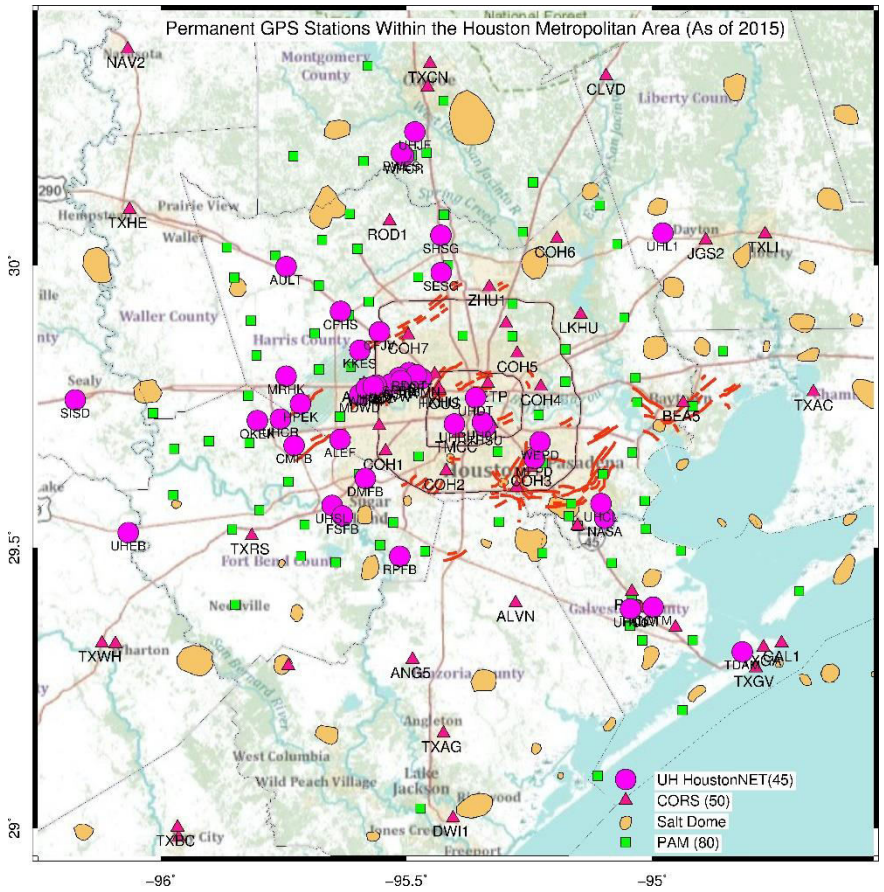
170 Permanent GPS

Harris-Galveston Subsidence District (80)

Texas Department of Transportation 15+
NGS, Houston City, SmartNet, others

University of Houston

HoustonNet



NSF MRI (Major Research Instrumentation Grant--HoustonNET). MRI: Acquisition of GPS Equipment for Establishing a Continuously Operating Dense GPS Network in Houston Metropolitan Area for Urban Natural Hazards Study (September 1, 2012---August 30, 2014). PI: Guoquan Wang, Co-PIs: Shuhab Khan (Geosciences), Barry Lefer (Atmospheric Science), Thomas Hsu (Civil Engineering), Ramesh Shrestha (Geodetic Imaging), Paul Mann (Natural Hazards), William Carter (Survey Technology Engineering), Yi-Lung Mo (Structural Engineering), Hassan Moghaddam (Land Surveying), Craig Glennie (Airborne Surveying), Hyongki Lee (Remote Sensing).

- **50 GPS**
- **Subsidence, faulting, and salt dome uplift**
- **Hurricane intensity forecasting**
- **Civil engineering community---buildings, bridges, dams, sea walls**

Journal of Geodetic Science

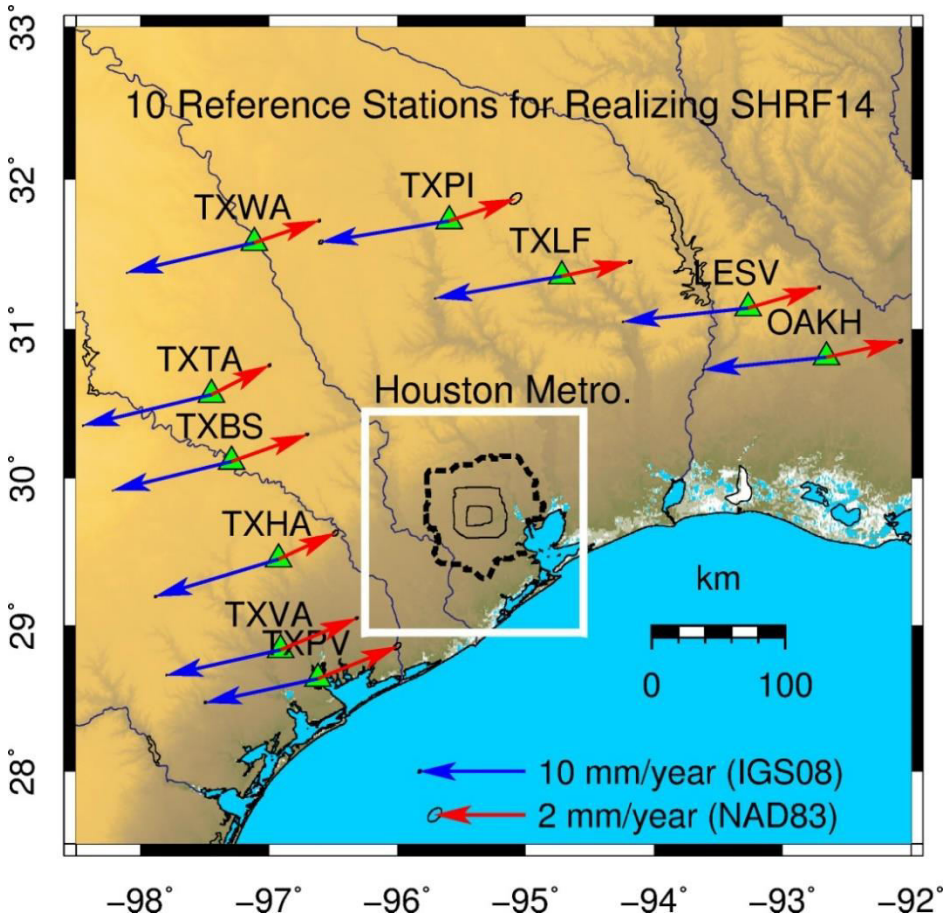
• 3(3) • 2013 • 188-202 DOI: 10.2478/jogs-2013-0021 •

A stable reference frame for the study of ground deformation in the Houston metropolitan area, Texas

Research Article

G. Wang*, J. Yu, J. Ortega, G. Saenz, T. Burrough and R. Neill

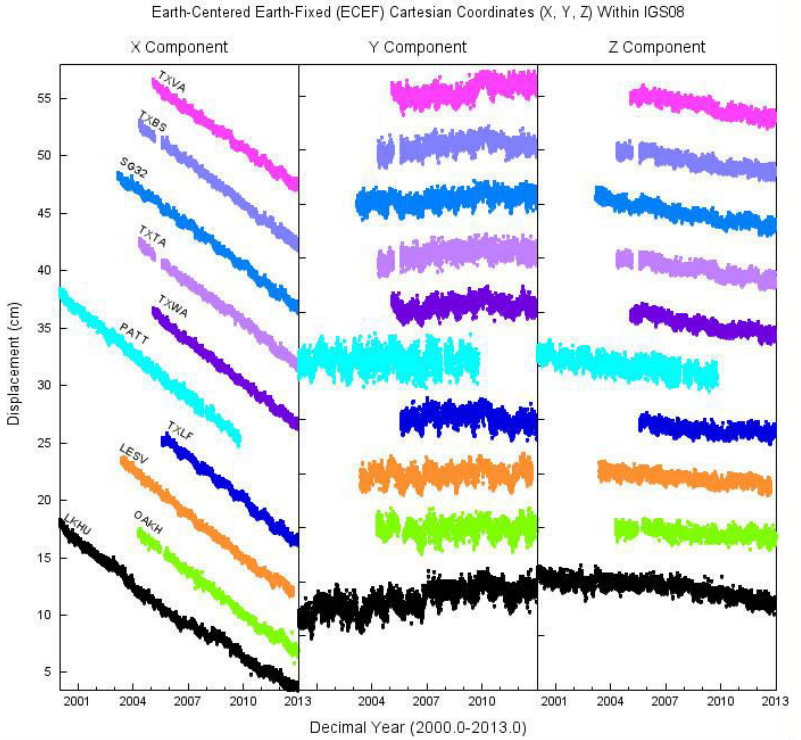
SHRF12
SHRF14



Helmert Transformation

$$X_{Local} = C + sRX_{Global}$$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^B = \begin{bmatrix} c_x \\ c_y \\ c_z \end{bmatrix} + (1 + s \times 10^{-6}) \cdot \begin{bmatrix} 1 & -r_z & r_y \\ r_z & 1 & -r_x \\ -r_y & r_x & 1 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^A$$



7 years: 2005-2012
9 years: 2005-2014

Wang et al., 2013, 2015

14-Parameter Similarity Transformation

$$X(t)_{SHRF} = T_X\ (t) + [1 + s(t)] \cdot X(t)_{IGS08} + R_Z(t) \cdot Y(t)_{IGS08} - R_Y(t) \cdot Z(t)_{IGS08}$$

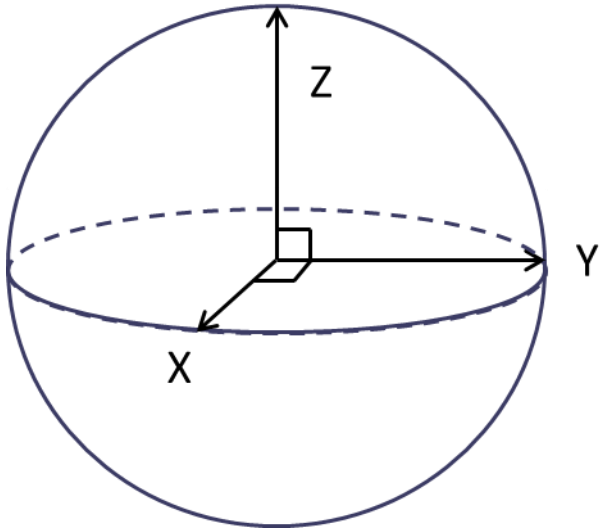
$$Y(t)_{SHRF} = T_Y\ (t) - R_Z(t) \cdot X(t)_{IGS08} + [1 + s(t)] \cdot Y(t)_{IGS08} + R_X(t) \cdot Z(t)_{IGS08}$$

$$Z(t)_{SHRF} = T_Z\ (t) + R_Y(t) \cdot X(t)_{IGS08} - R_X(t) \cdot Y(t)_{IGS08} + [1 + s(t)] \cdot Z(t)_{IGS08}$$

(1) Translation along the respective axis (in meters)

(2) Differential Scaling of the respective axis (ppb)

(3) Counterclockwise Rotations (in radians)



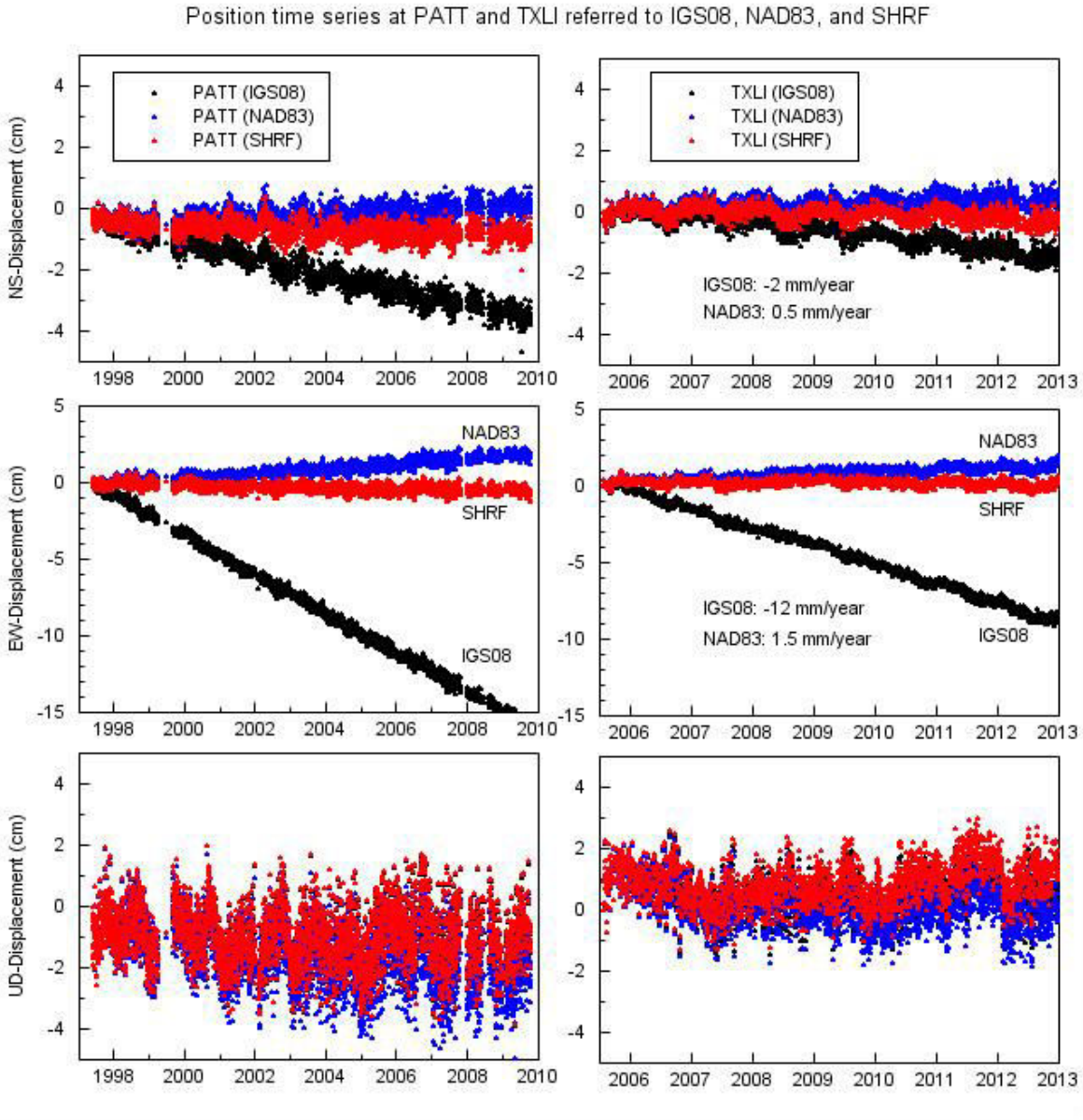
14-Transformation Parameters

Transformation Parameter	Unit	IGS08 to SHRF $t_0 = 2012$	IGS08 to NAD83(2011) $t_0 = 1997$*
$T_x(t_0)$	cm	0.00000	99.34300
$T_y(t_0)$	cm	0.00000	-190.33100
$T_z(t_0)$	cm	0.00000	-52.65500
$R_x(t_0)$	mas	0.00000	25.91467
$R_y(t_0)$	mas	0.00000	9.42645
$R_z(t_0)$	mas	0.00000	11.59935
$s(t_0)$	ppb	0.00000	1.71504
dT_x	cm/year	-1.07250	0.07900
dT_y	cm/year	-1.05876	-0.06000
dT_z	cm/year	-3.54574	-0.13400
dR_x	mas/year	1.15720	0.06667
dR_y	mas/year	-0.93885	-0.75744
dR_z	mas/year	-0.33224	-0.05133
ds	ppb/year	1.37220	-0.10201

NGS

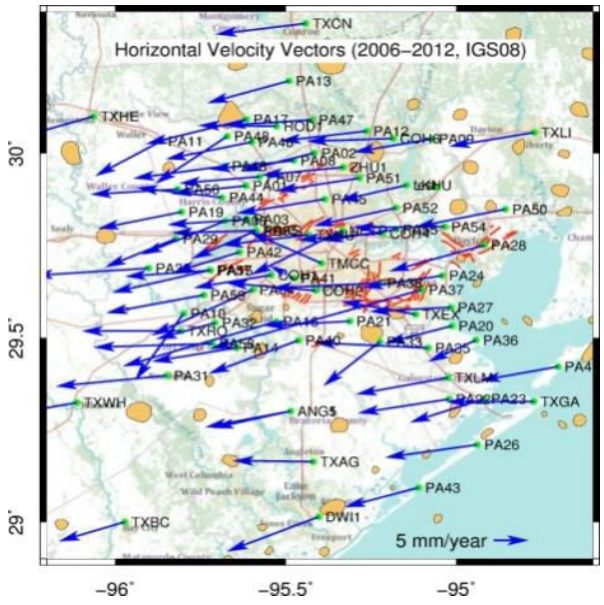
*Pearson and Snay (2013), Table 7

A comparison of positional time series with respect to three reference frames: IGS08, NAD83, SHRF

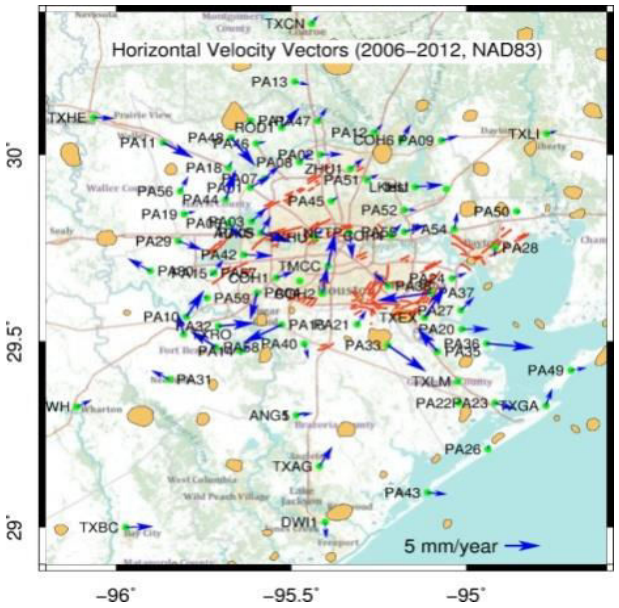


Stable: v=0

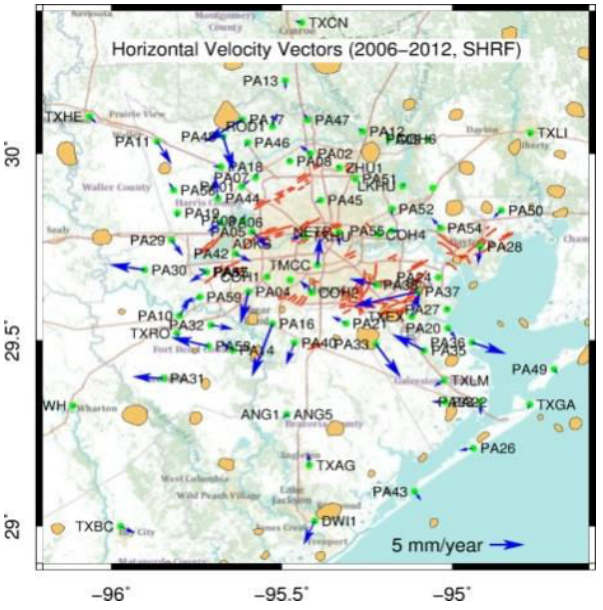
Horizontal Velocity Vectors Referred to: IGS08, NAD83, SHRF



Global-Scale (IGS08)

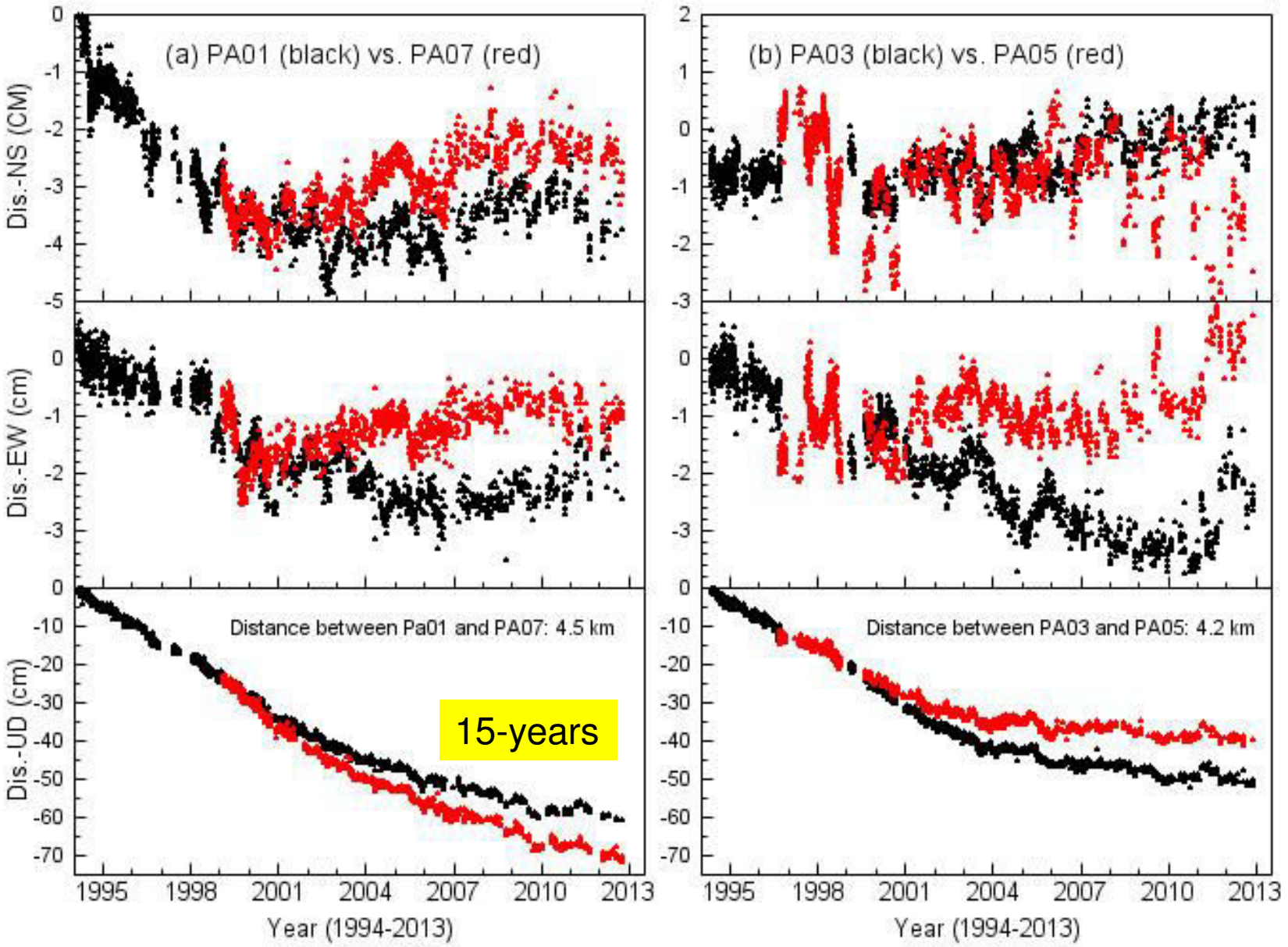


Regional-Scale (NAD83)

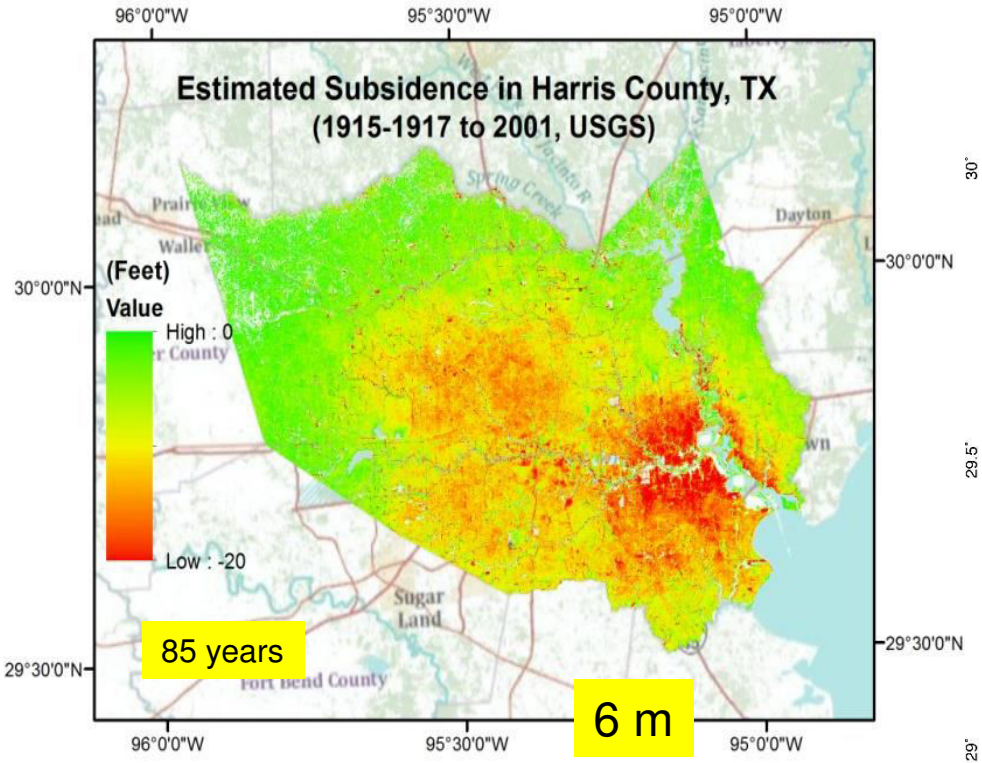


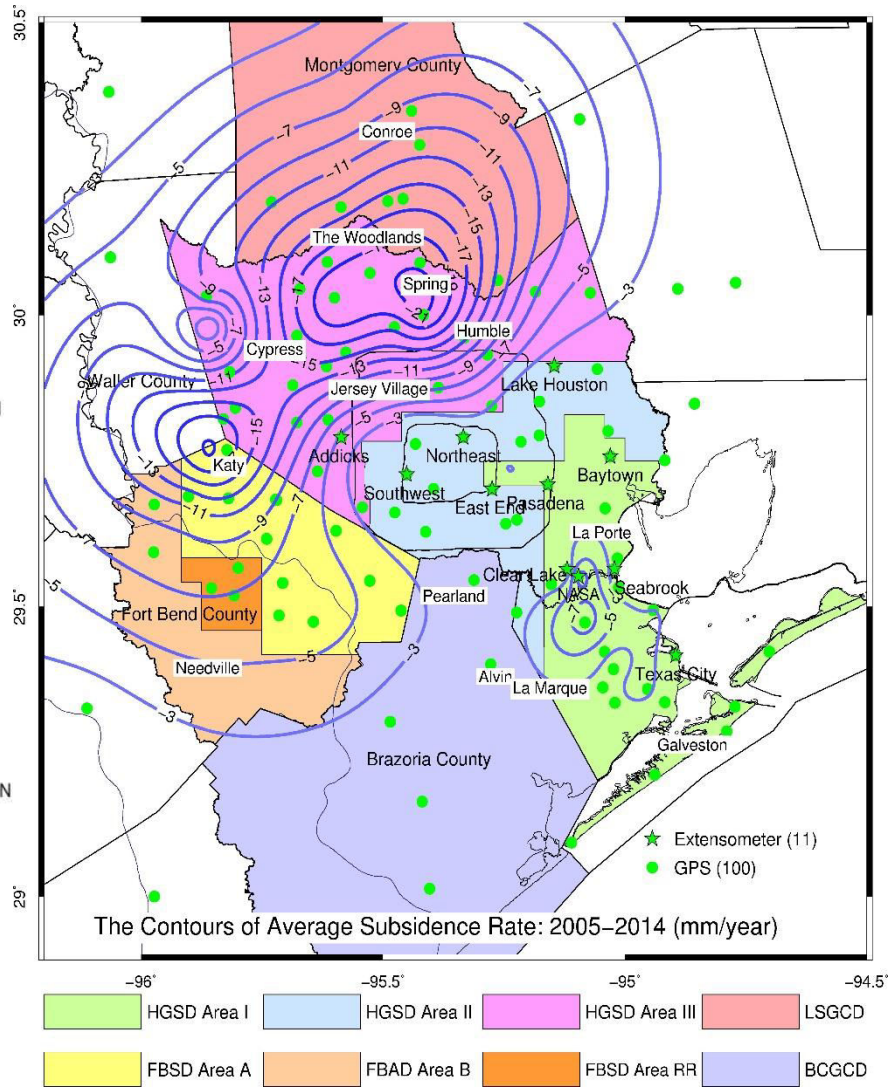
Local-Scale (SHRF)

Spatial and Temporal Variation of Subsidence



Recent Subsidence Mapping (2005-2014)





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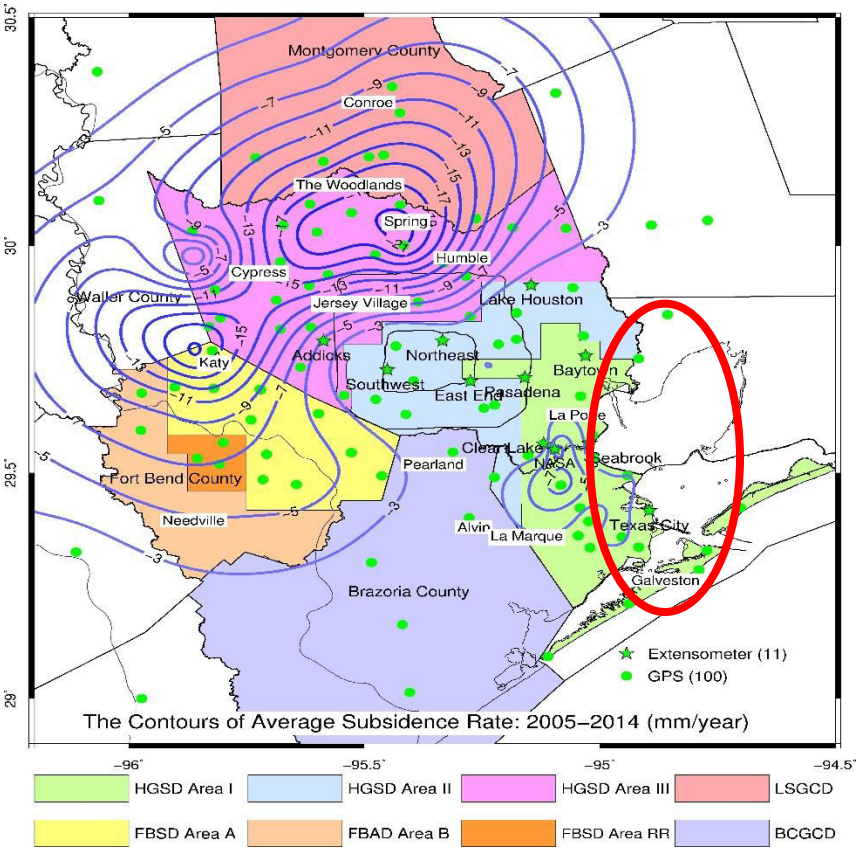
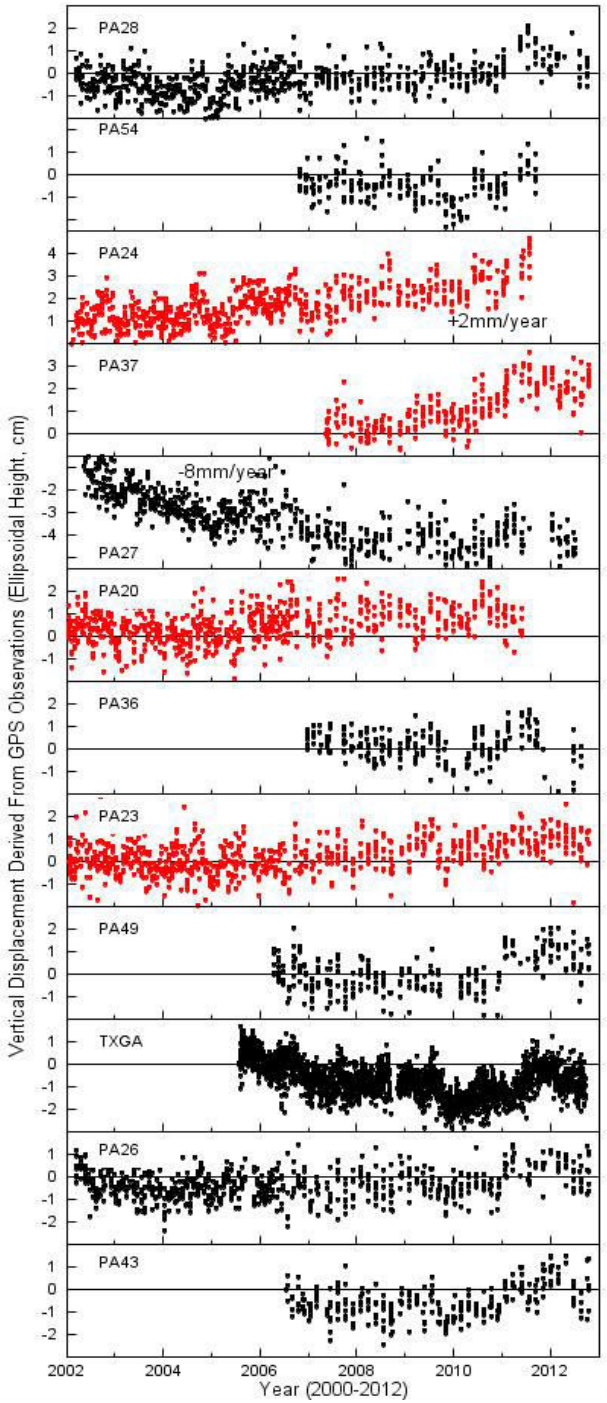
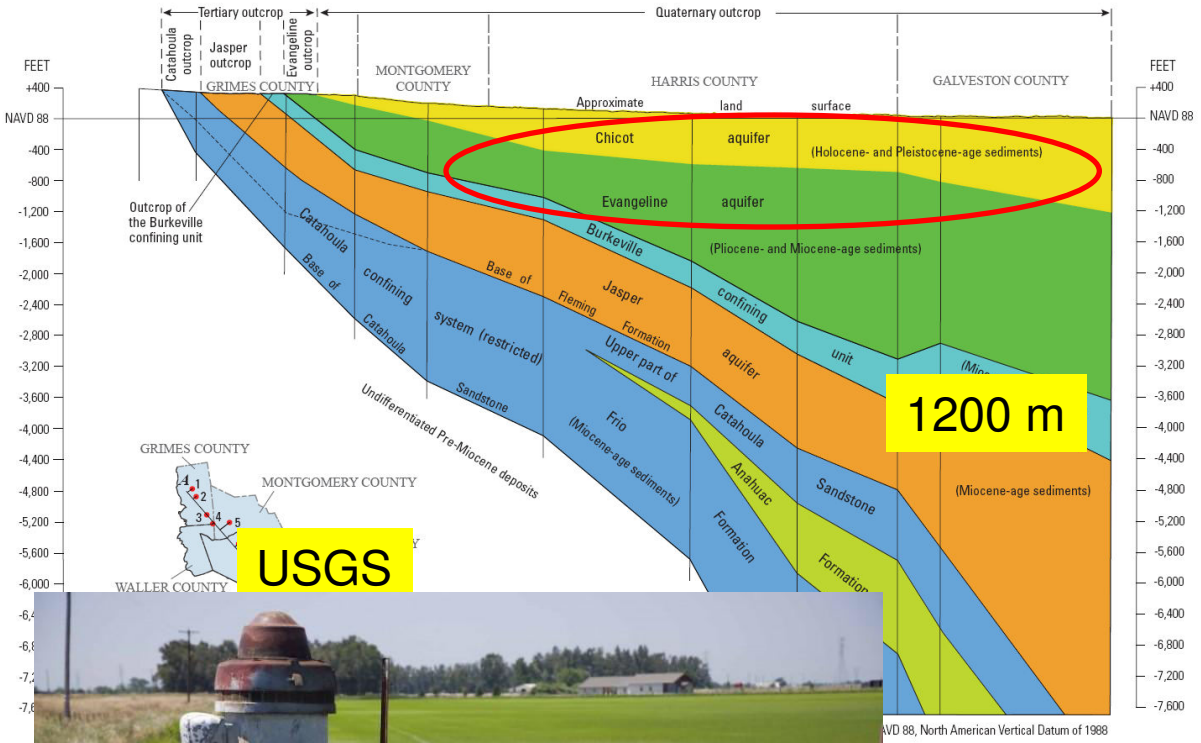
85 GPS (> 3 years) +11 Extensometers

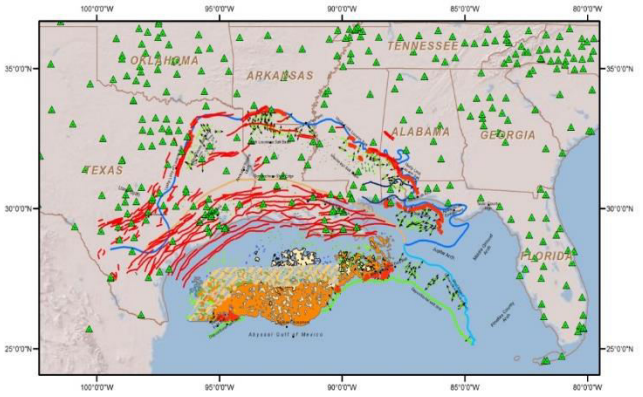
Land uplift


Montgomery County
Conroe
The Woodlands
Spring
Humble
Cypress
Waller County
Jersey Village
Lake Houston
Addicks
Northeast
Southwest
East End
Pasadena
Bayto
La Porte
Clear Lake
NASA
Seabrook
Pearland
Fort Bend County
Needville
Alvin
La Marque
Texas City
Galveston
Brazoria County
Katy
Extensometer (11)
GPS (100)
The Contours of Average Subsidence Rate: 2005–2014 (mm/year)
30.5°
30°
29.5°
29°
−96°
−95.5°
−95°
−94.5°
HGSD Area I
HGSD Area II
HGSD Area III
LSGCD
FBSD Area A
FBAD Area B
FBSD Area RR
BCGCD

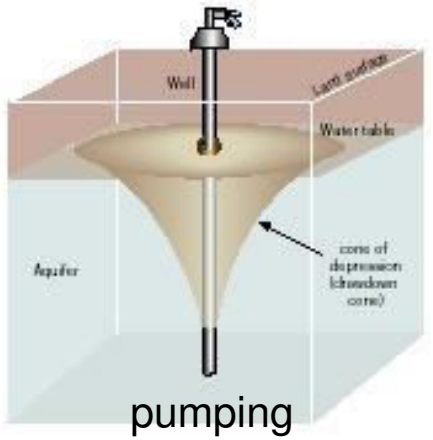

PA28
PA54
PA24
+2mm/year
PA37
-8mm/year
PA27
PA20
PA36
PA23
PA49
TXGA
PA26
PA43
Vertical Displacement Derived From GPS Observations (Ellipsoidal Height, cm)
2002
2004
2006
2008
2010
2012
Year (2000-2012)

Question 1: Is there deep-seated or fault-controlled subsidence in the Houston-Galveston area?





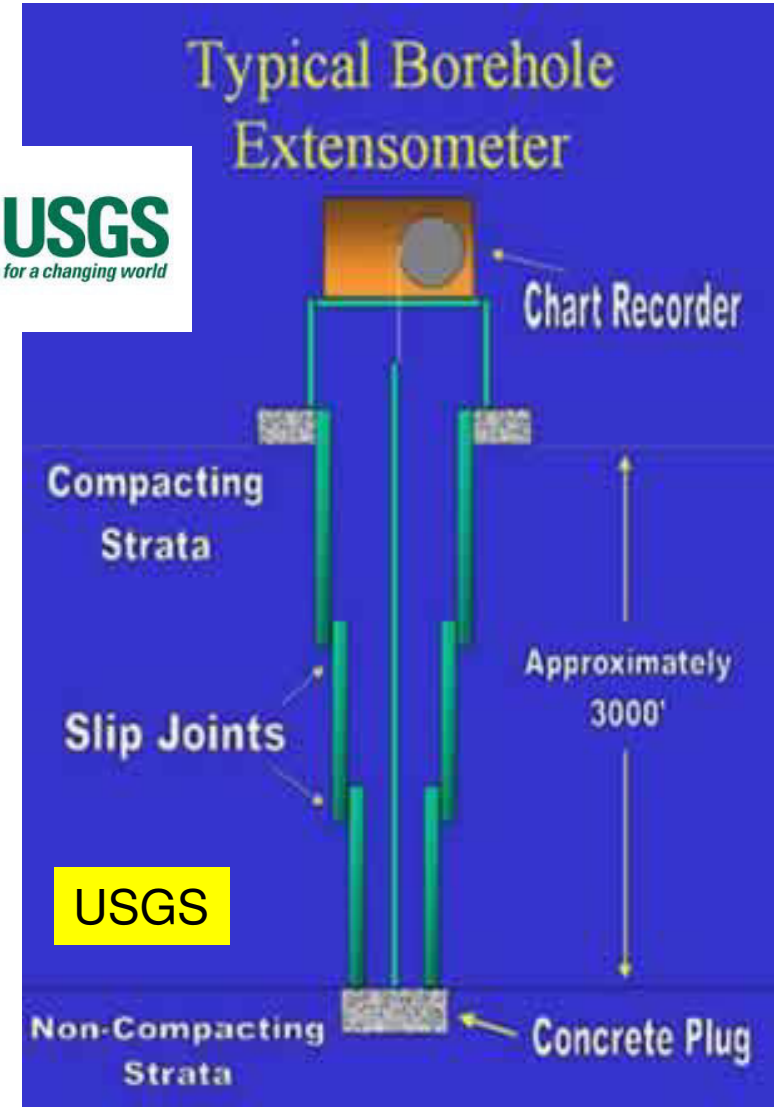
Subsidence vs. Faulting



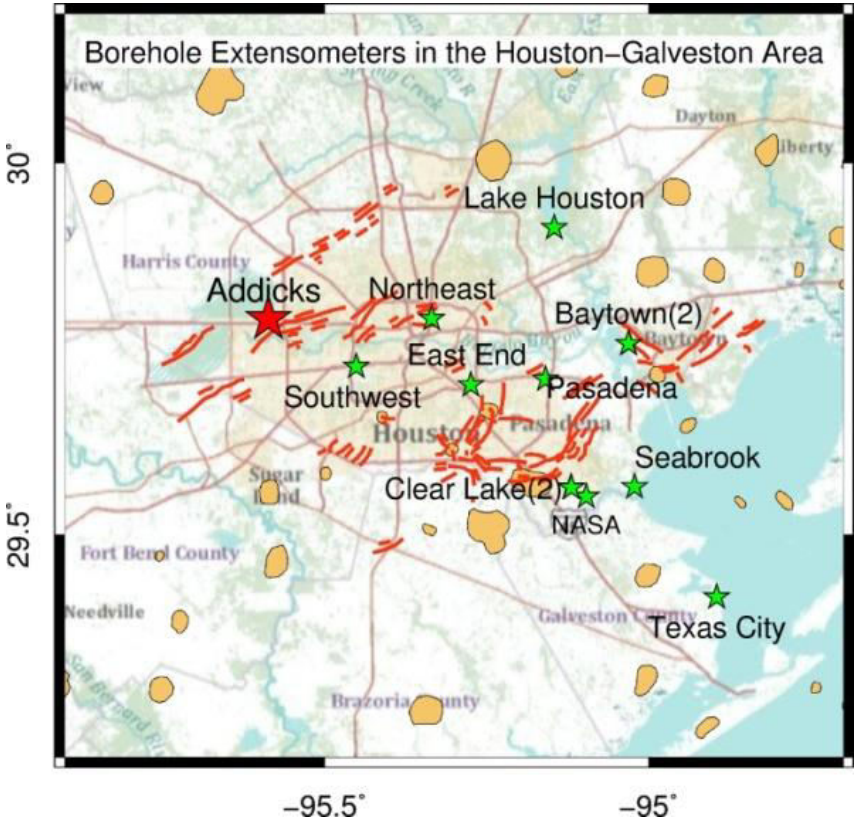
pumping

Subsidence---pumping (??%) + faulting (??%)

USGS Borehole Extensometers



Compaction meter



13 extensometers at 11 sites

40 years: 1974—2014

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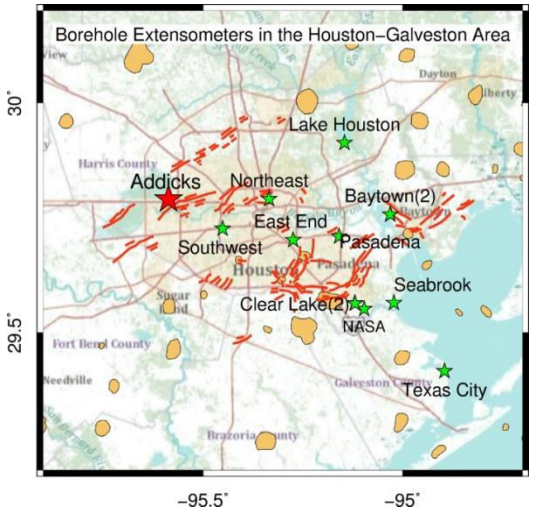
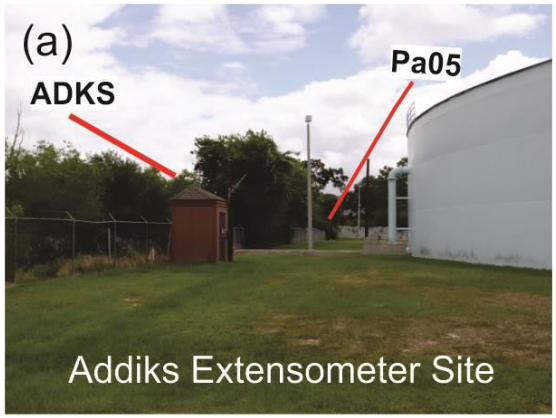
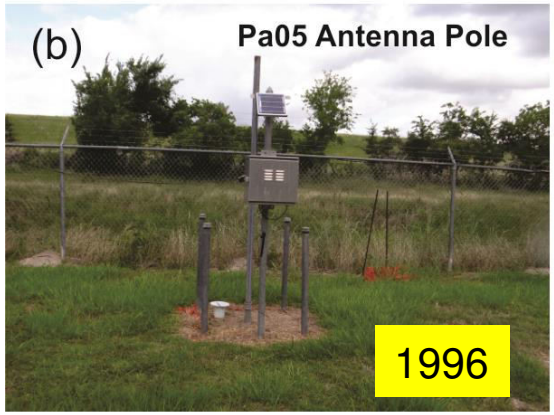
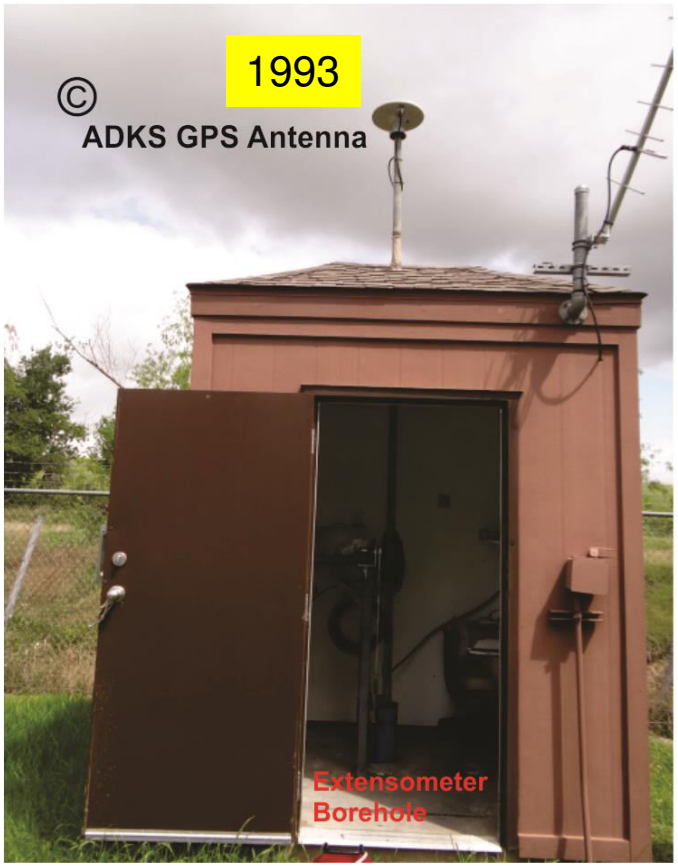
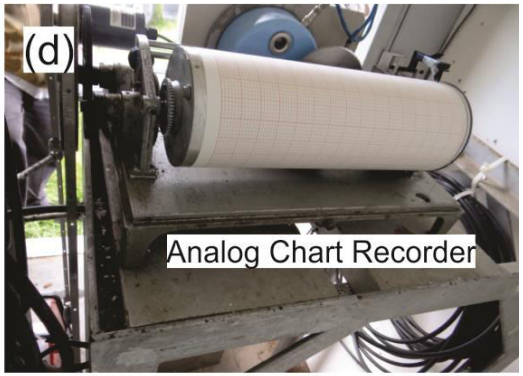
Addicks Borehole Extensometer (-549 m)

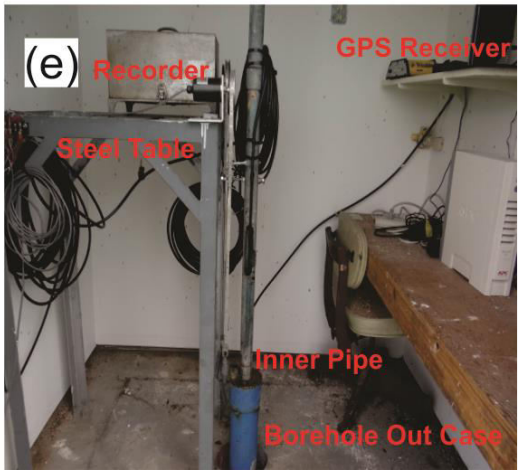




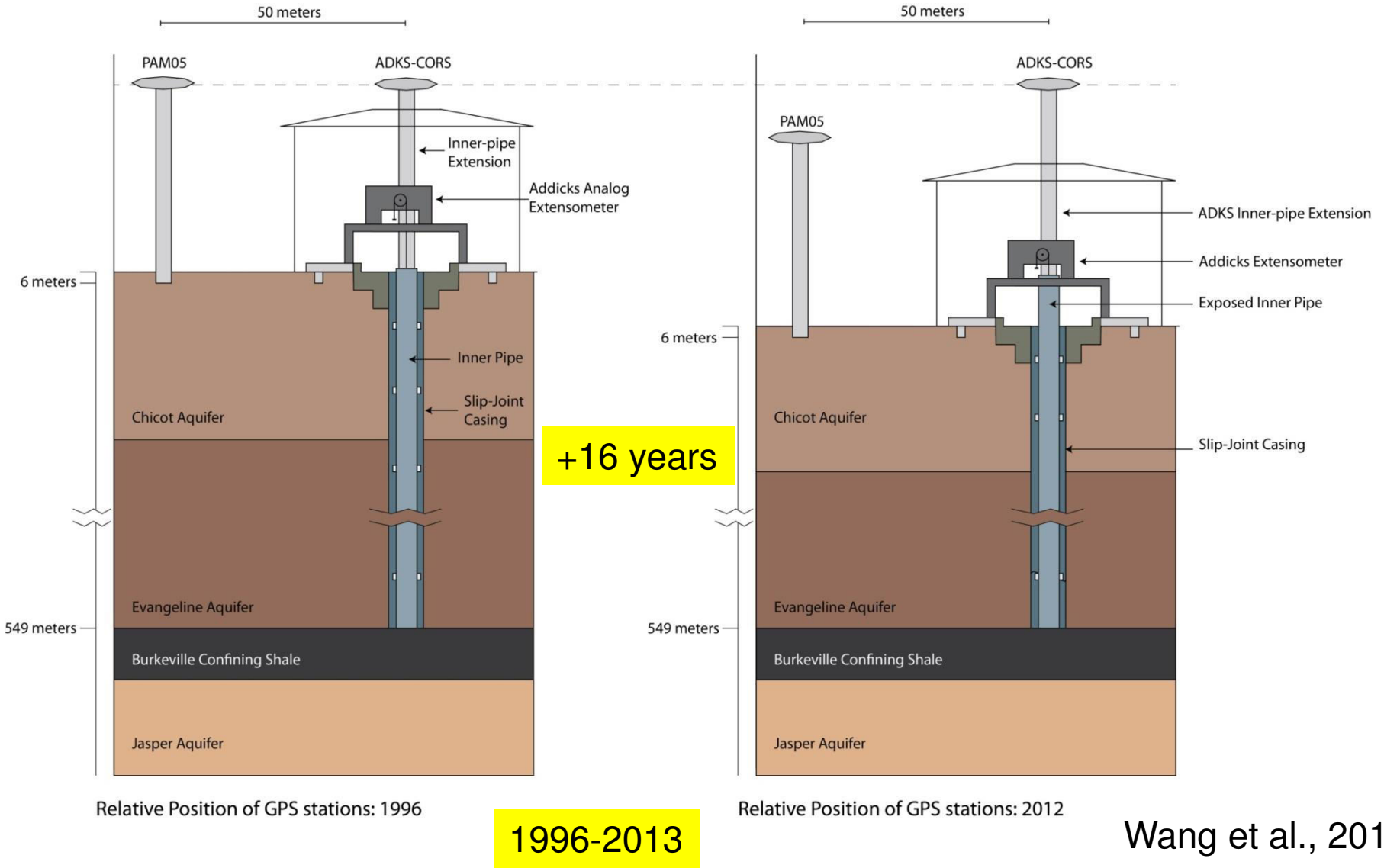




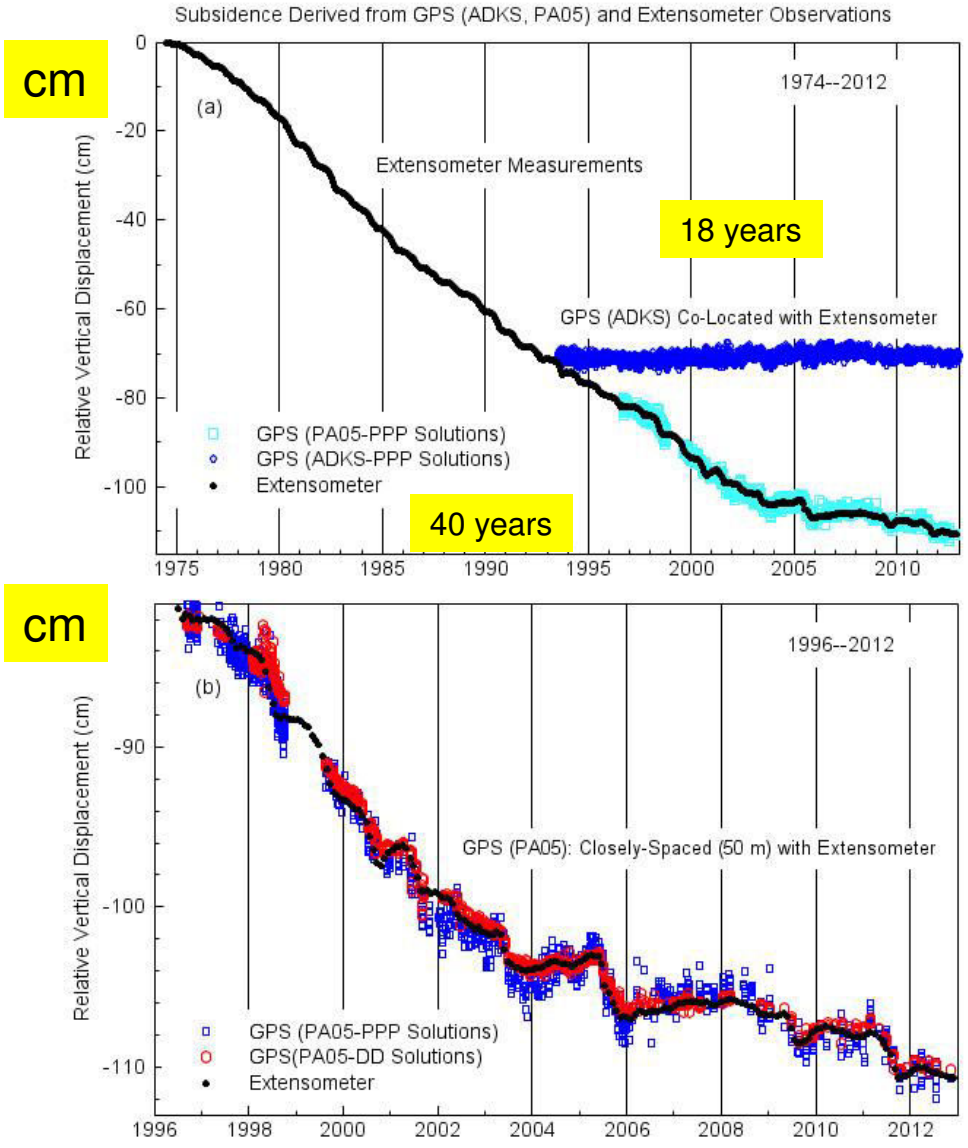


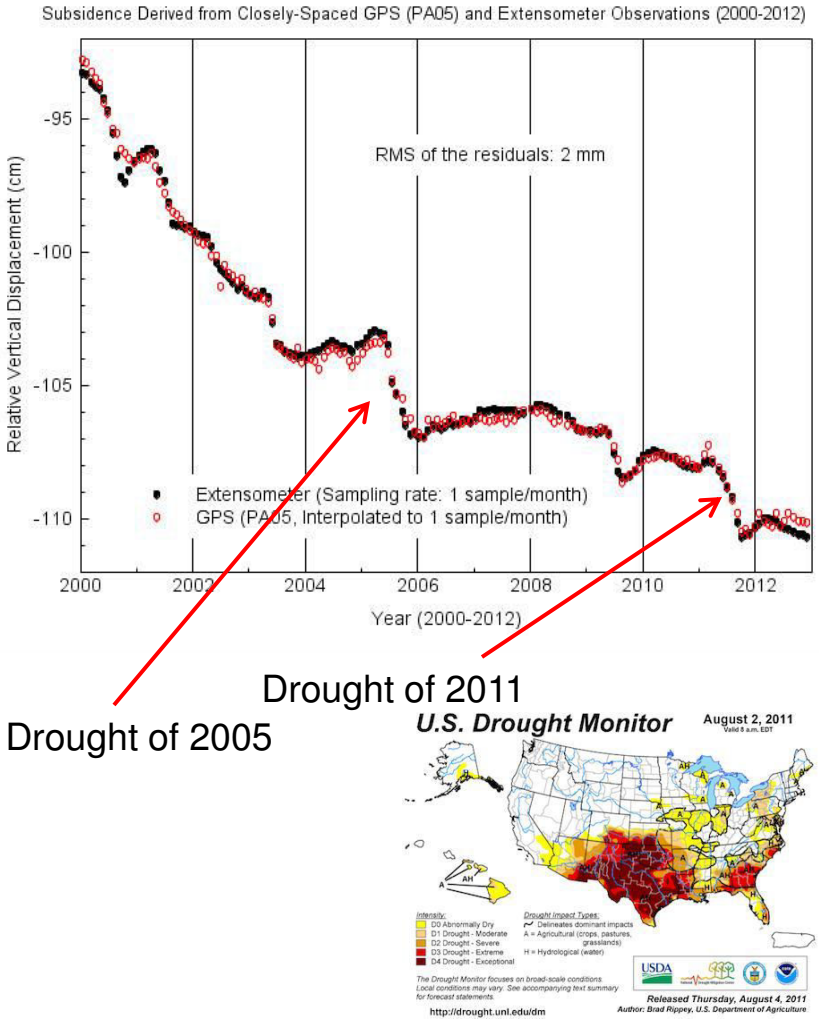


Co-Located GPS and Extensometer Monitoring Site (ADKS)



Wang et al., 2014





Conclusion: The compaction should occur in the sediments above -549 m.

Wang et al., 2014

Journal of Surveying Engineering

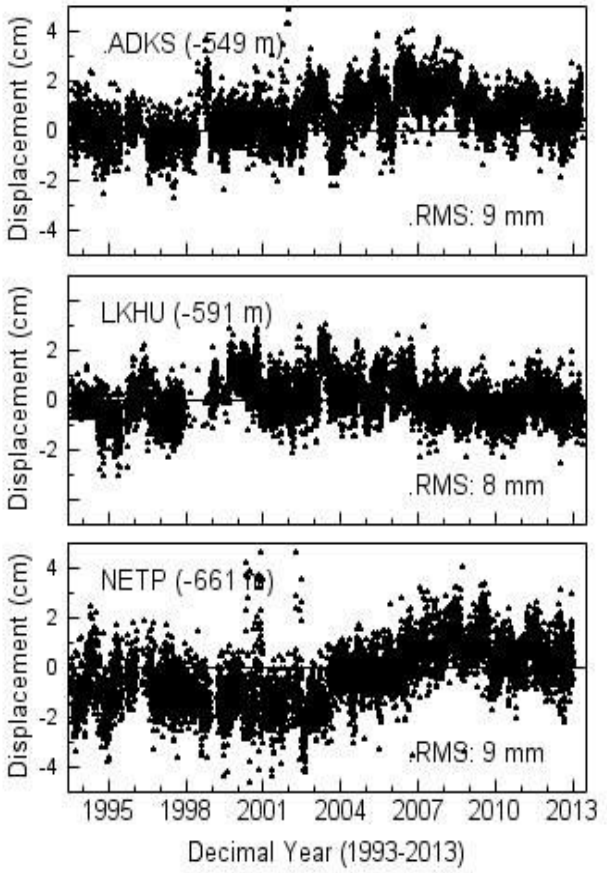
Co-located GPS and Extensometer Sites

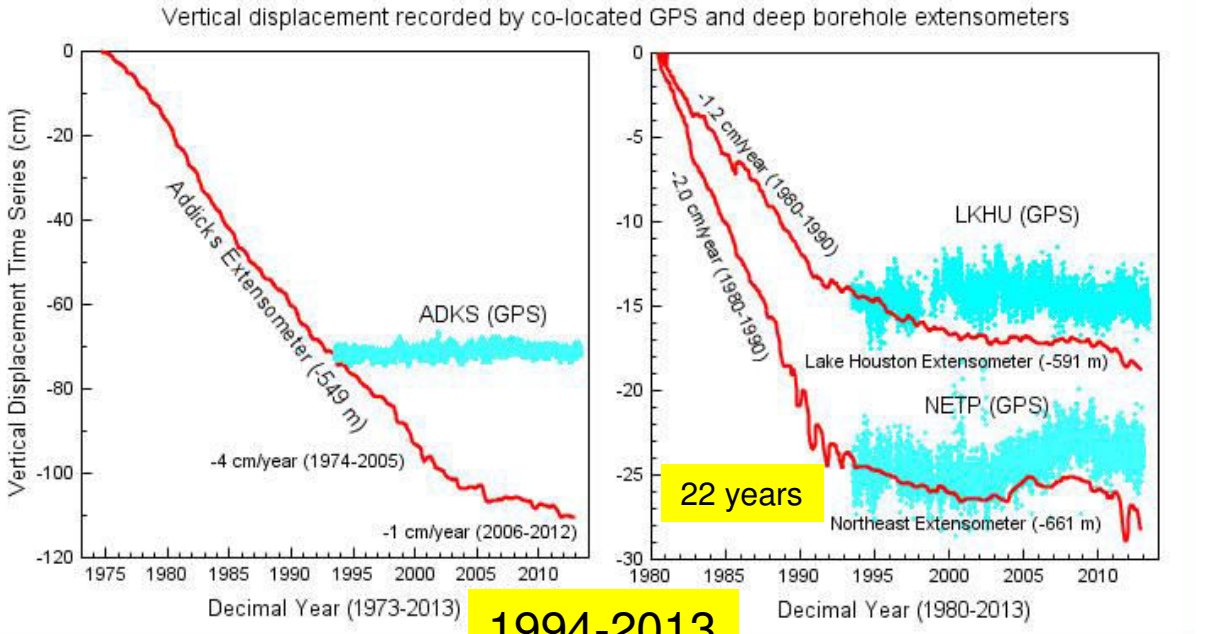
ADKS(-549 m)

NETP (-591 m)

LKHU (-661 m)

NGS-CORS





1994-2013

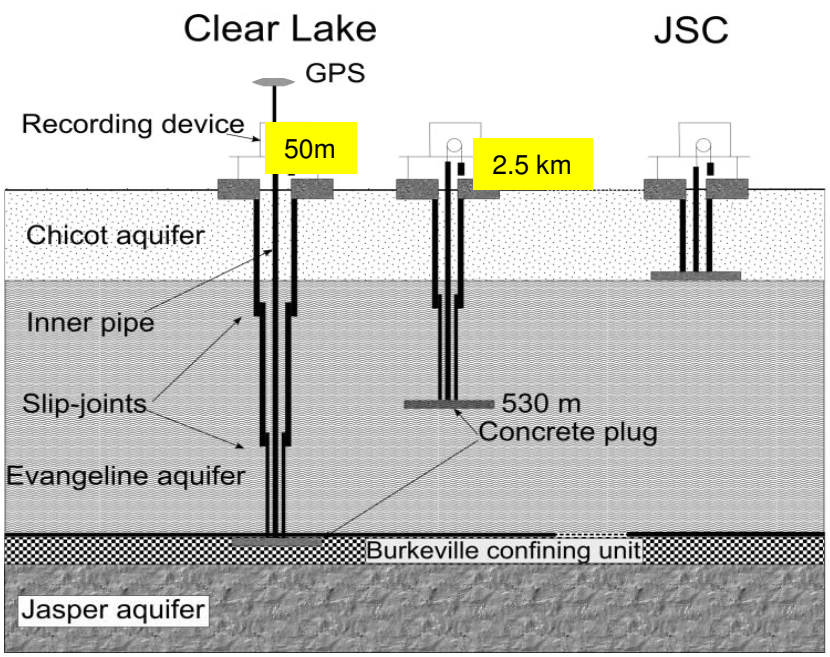
Conclusion: Compacted aquifers are limited to above -600 m

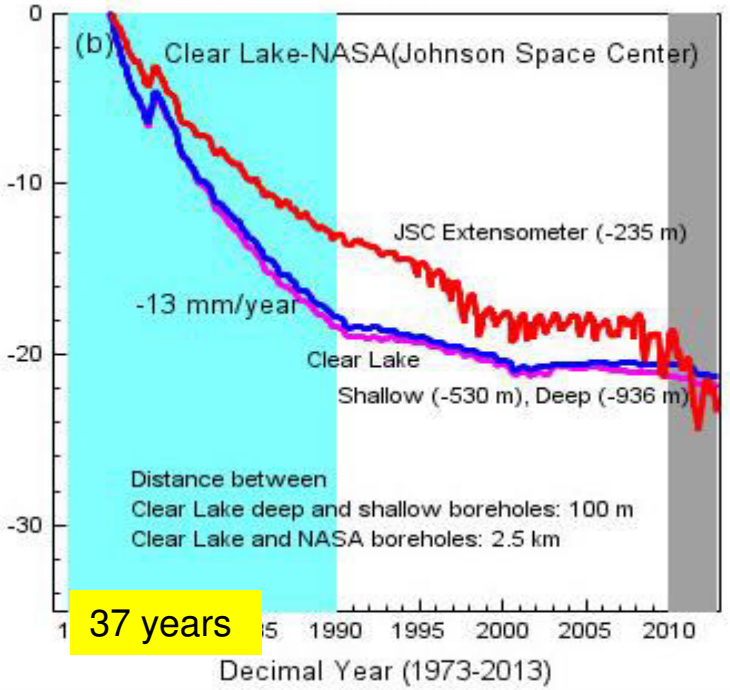
Clear Lake—Jonson Space Center Sites

Clear lake Deep Borehole (-936 m)

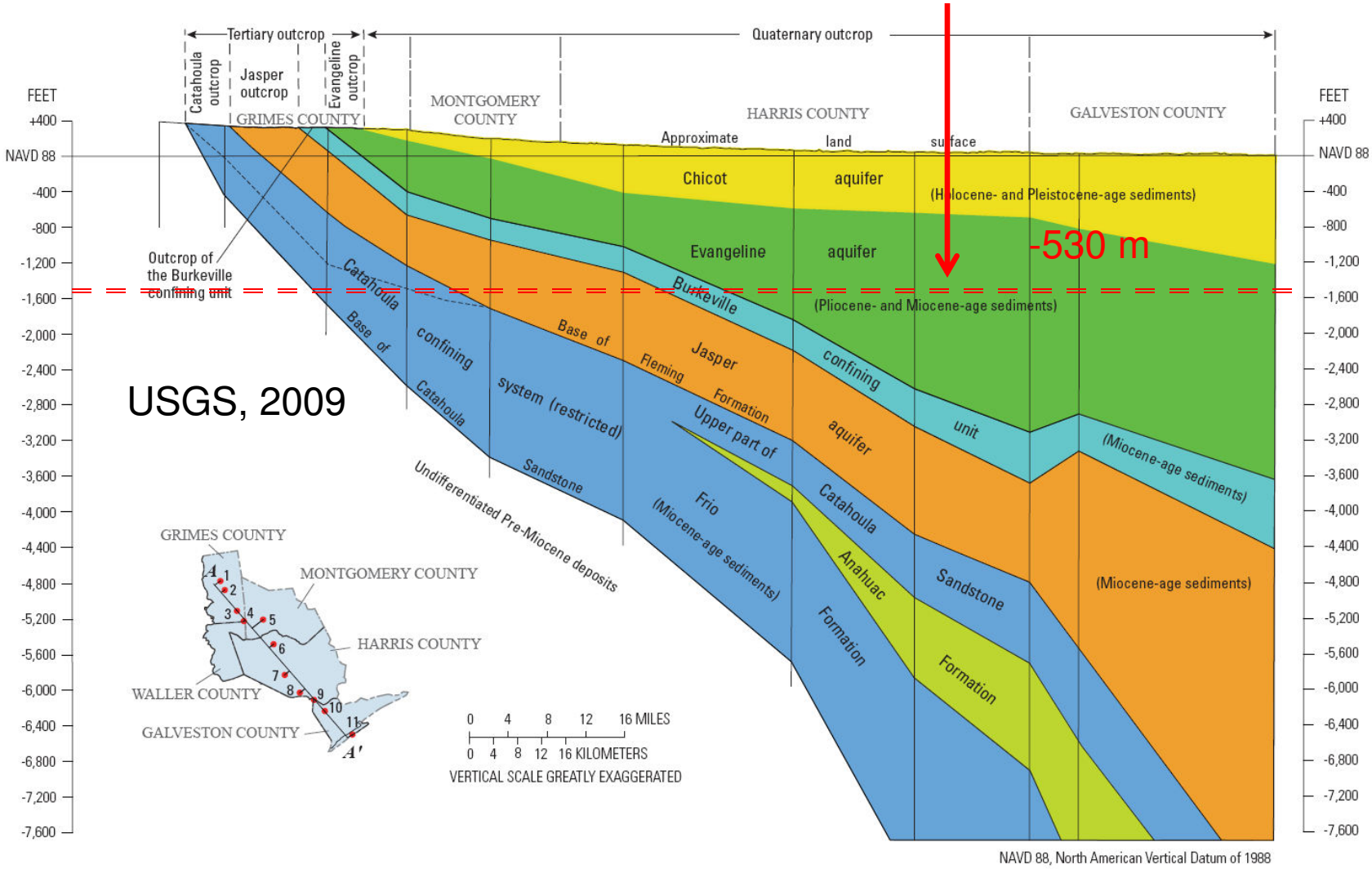
Clear lake Shallow Borehole (-530 m)

Jonson Space Center(-235 m)





Conclusion: There were compaction between -235 m to -530 m.
No compaction below -530 m.



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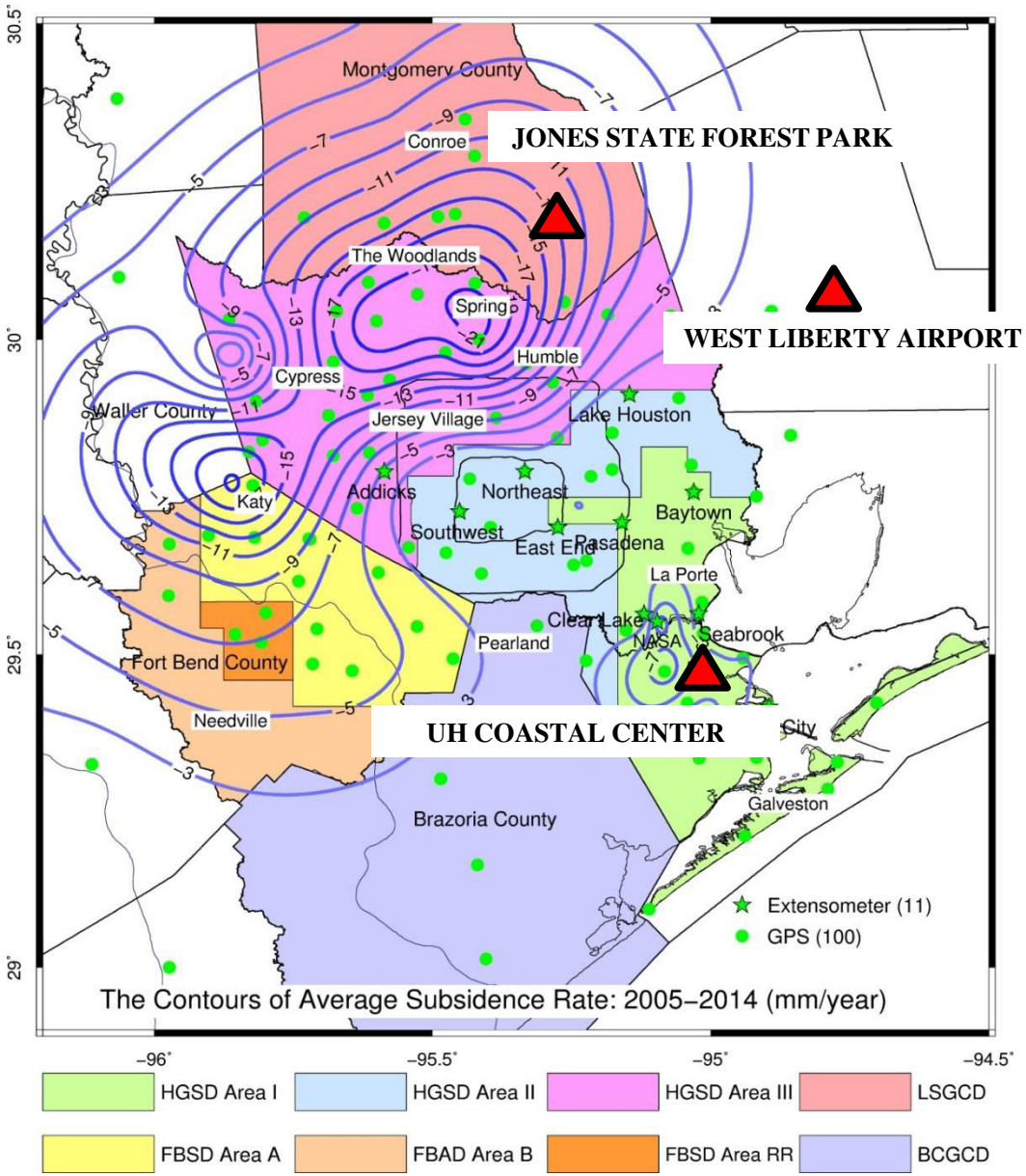
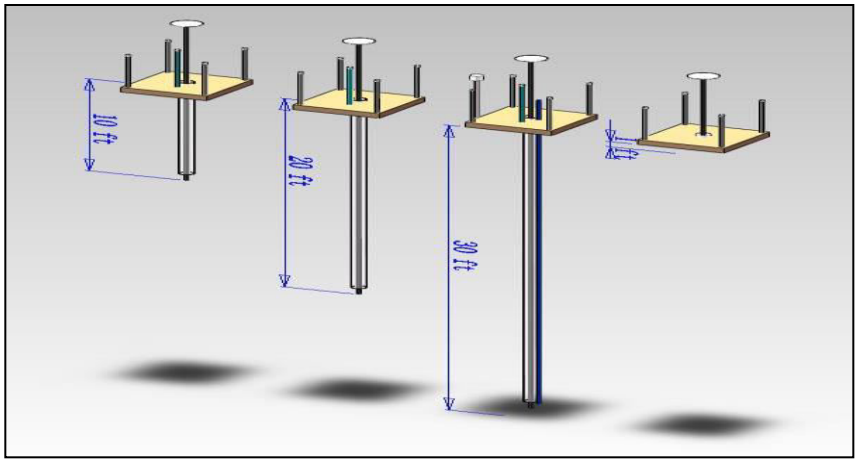
Conclusion: Only partial of the Evangeline aquifer had been compacted!

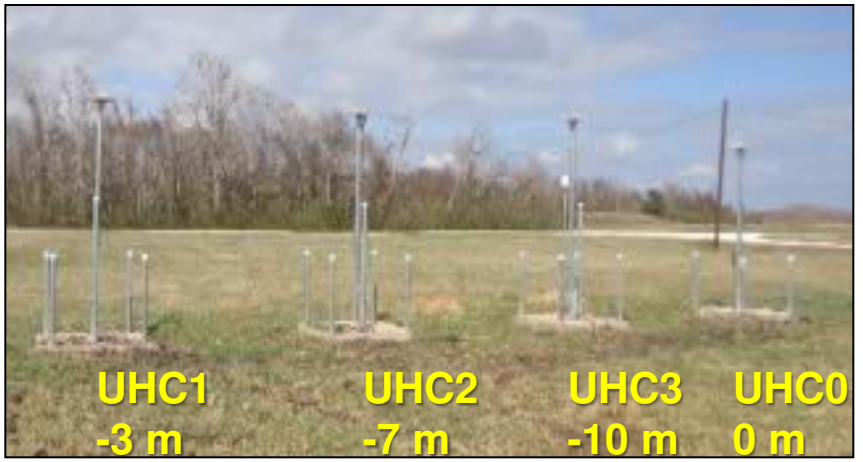
Compaction vs. Subsidence

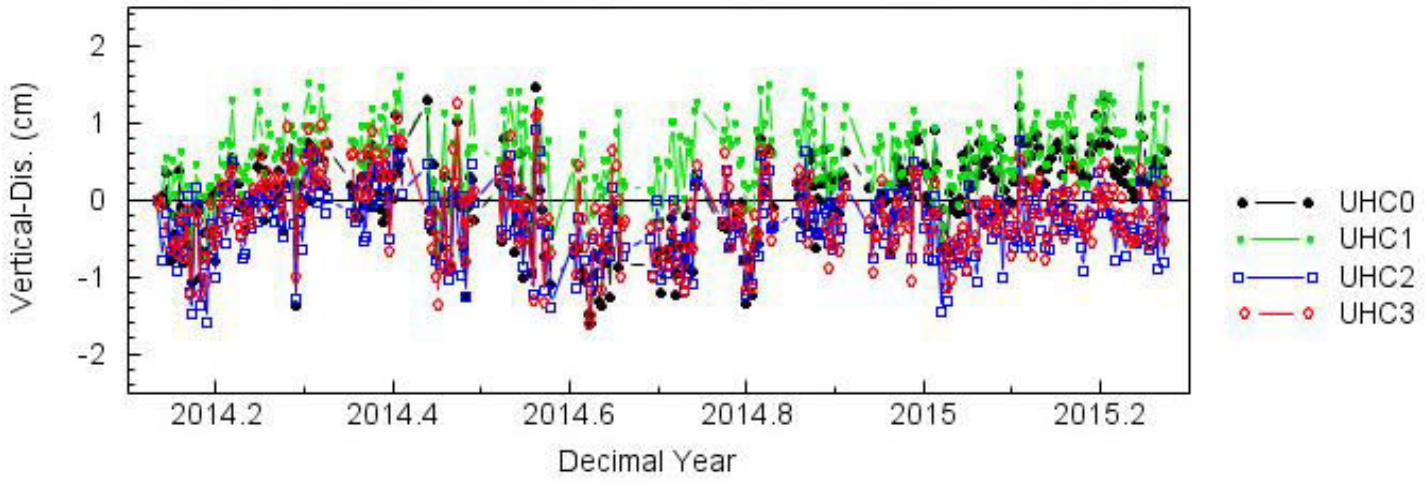


Double Pipes

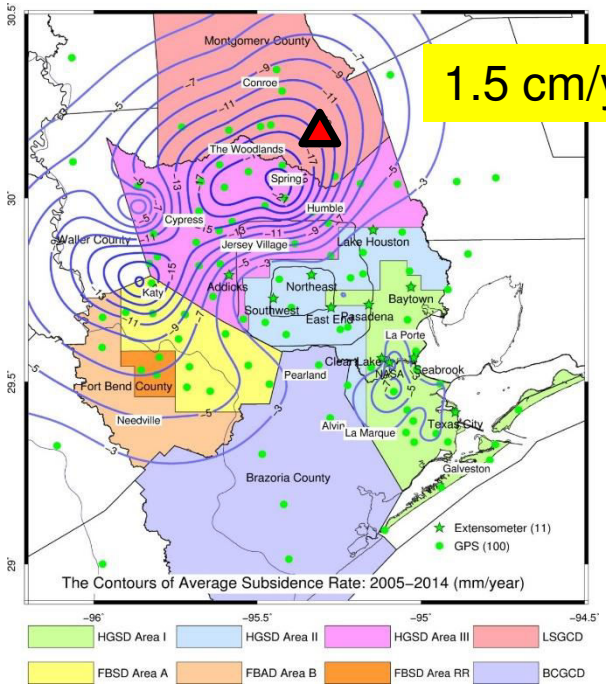
UH Coastal Center “Vertical” GPS Array



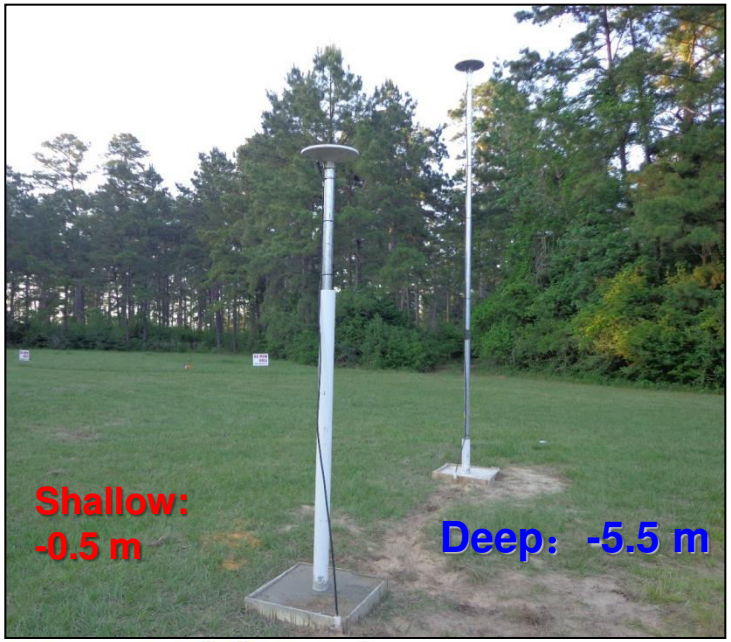


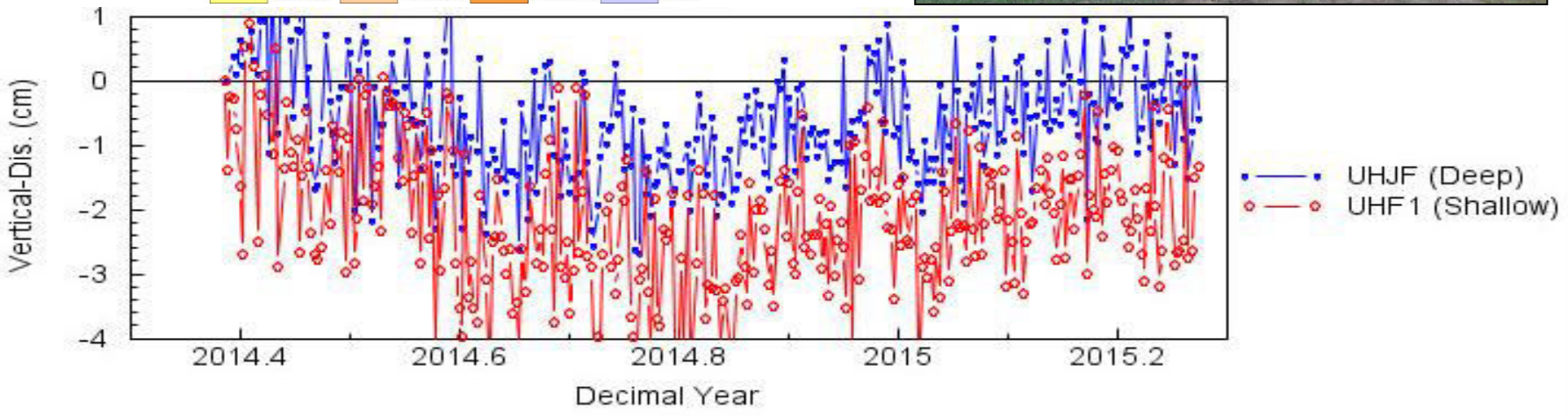


JONES STATE FOREST PARK GPS ARRAY

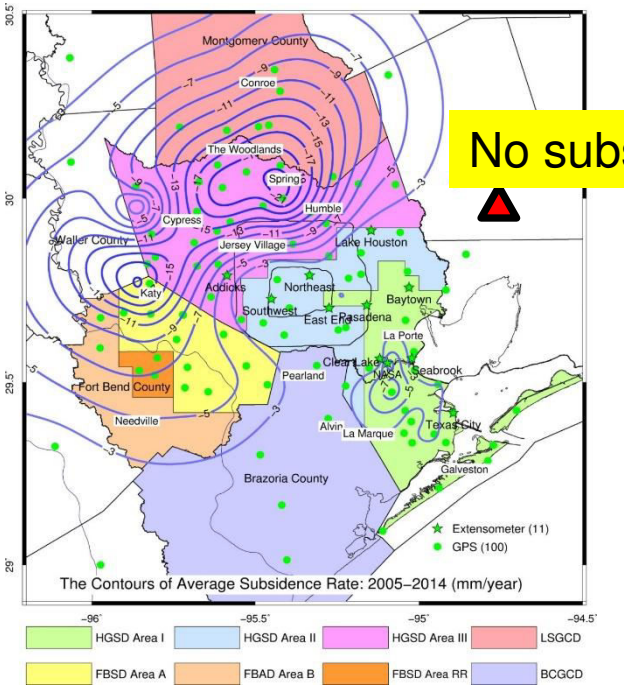


1.5 cm/year

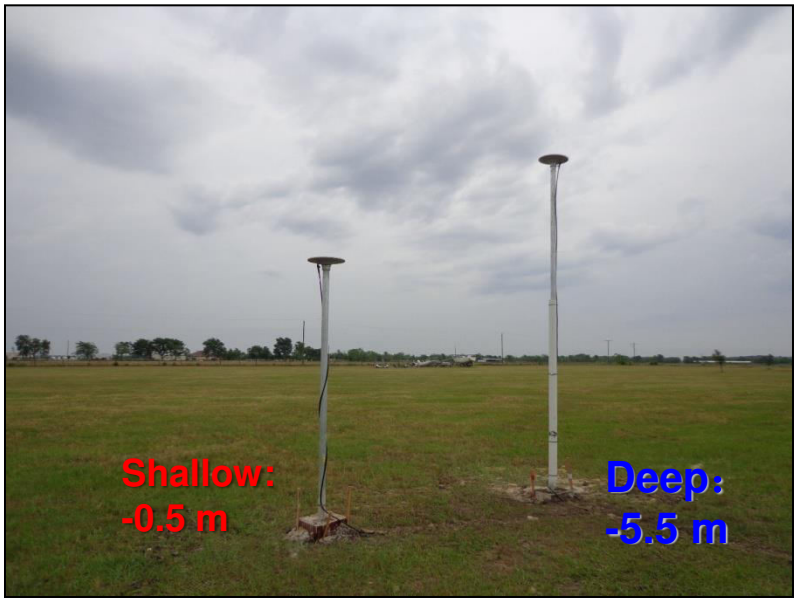


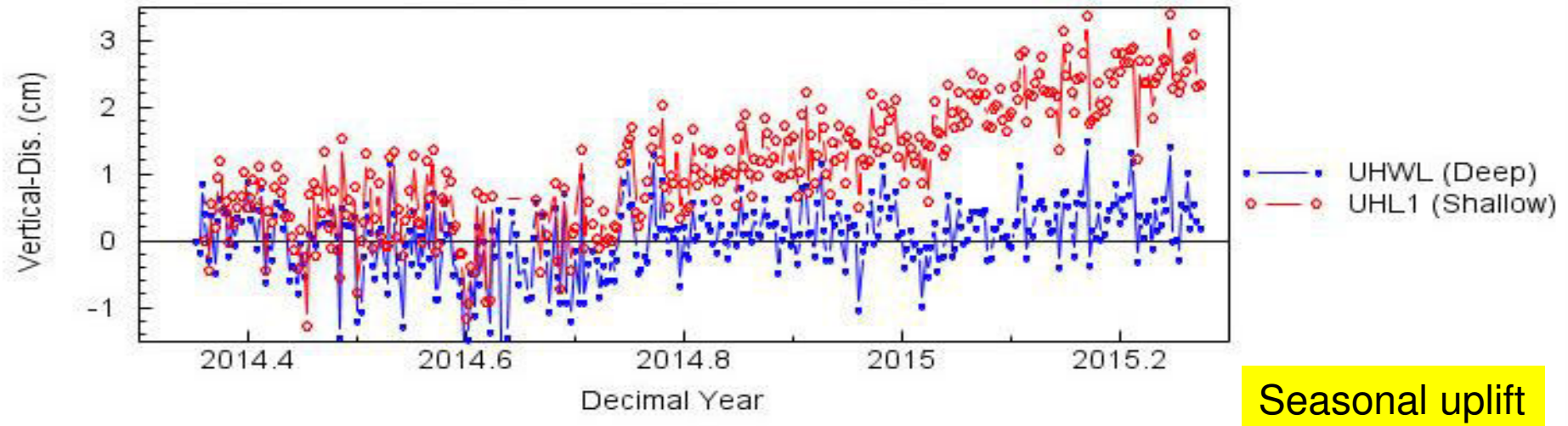


WEST LIBERTY AIRPORT GPS ARRAY



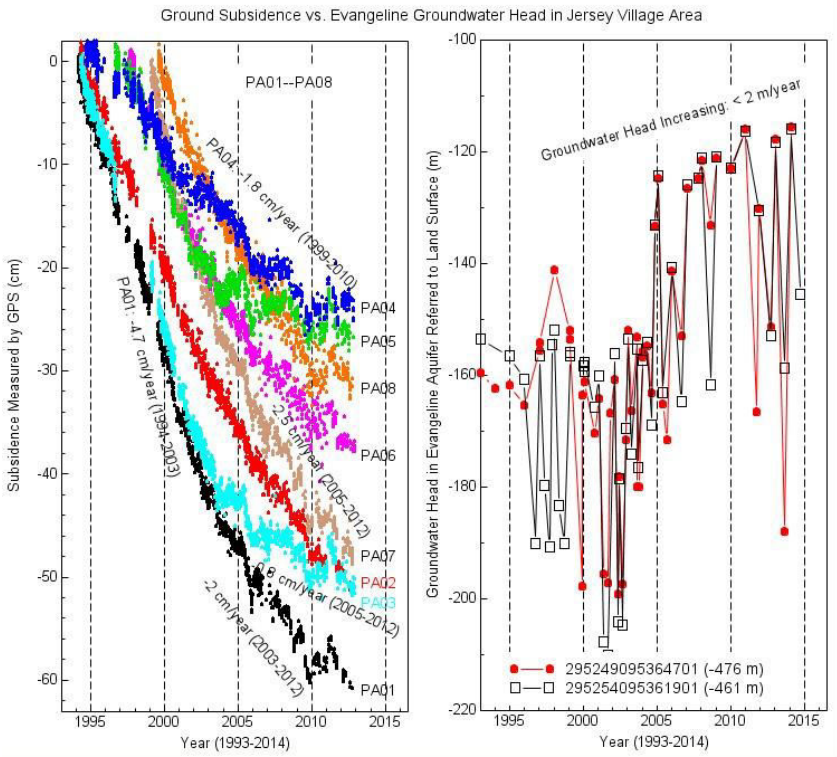
No subsidence

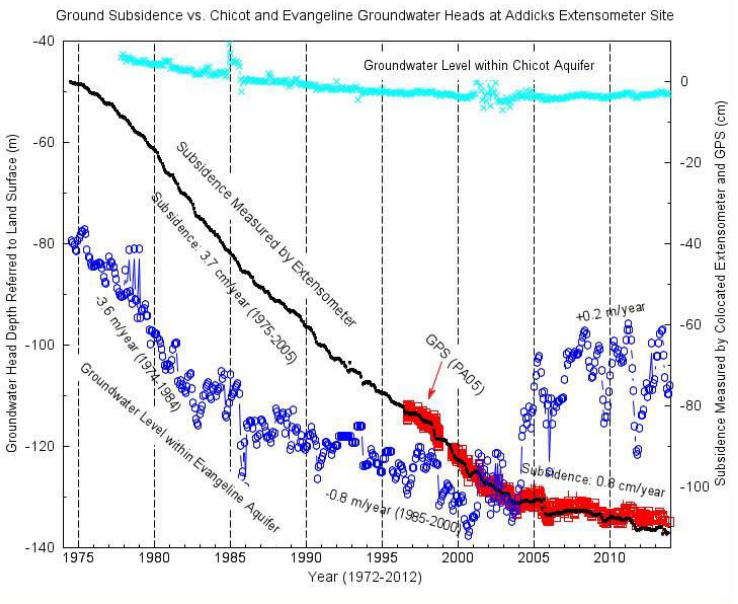


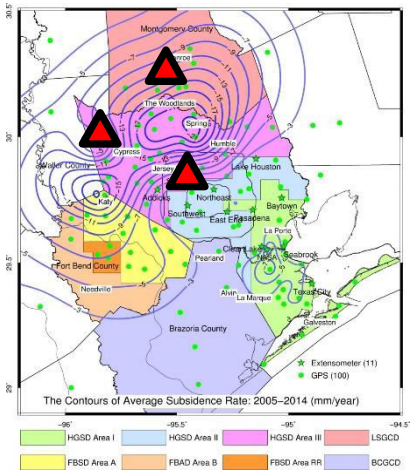


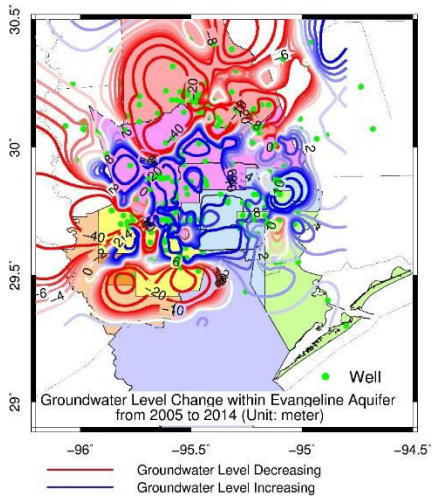
Seasonal uplift

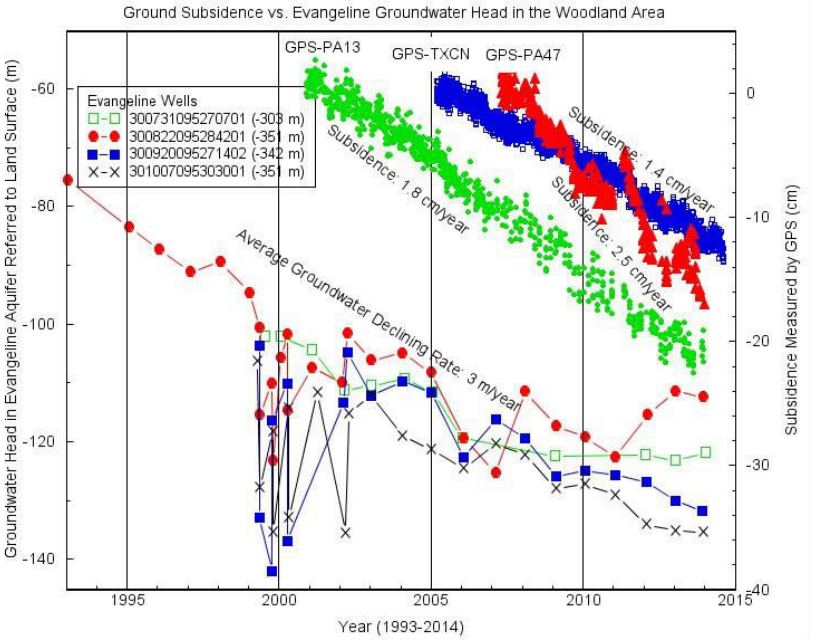
Question 2: When will the subsidence cease?



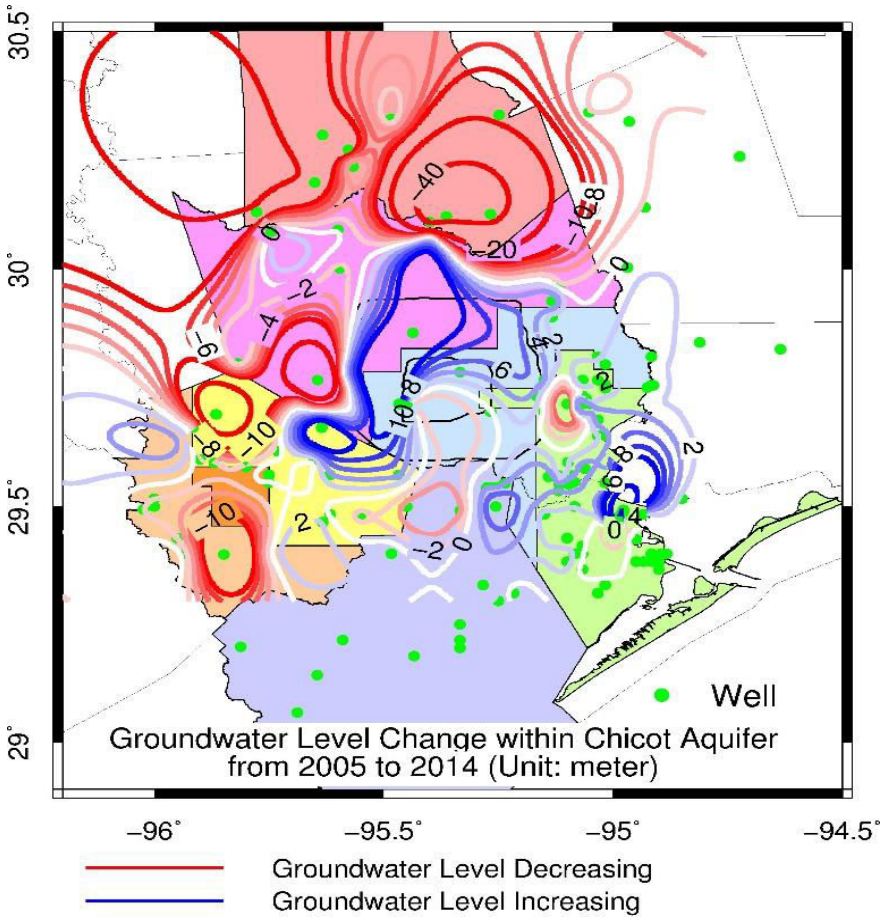


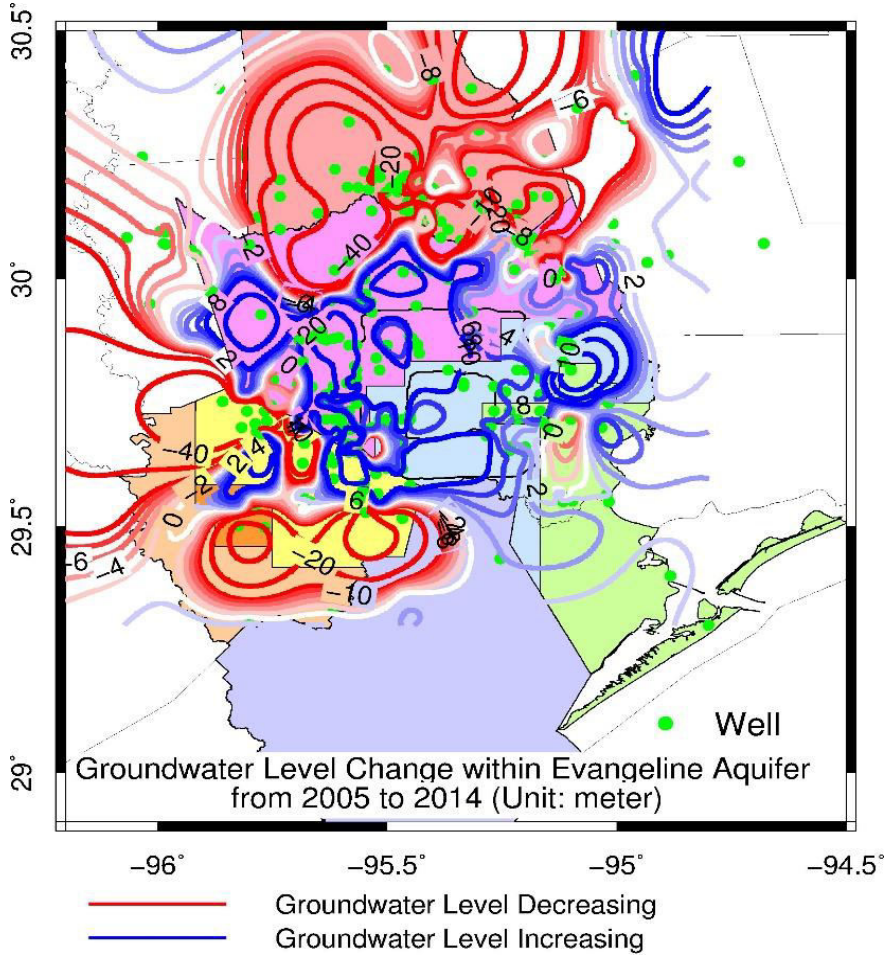




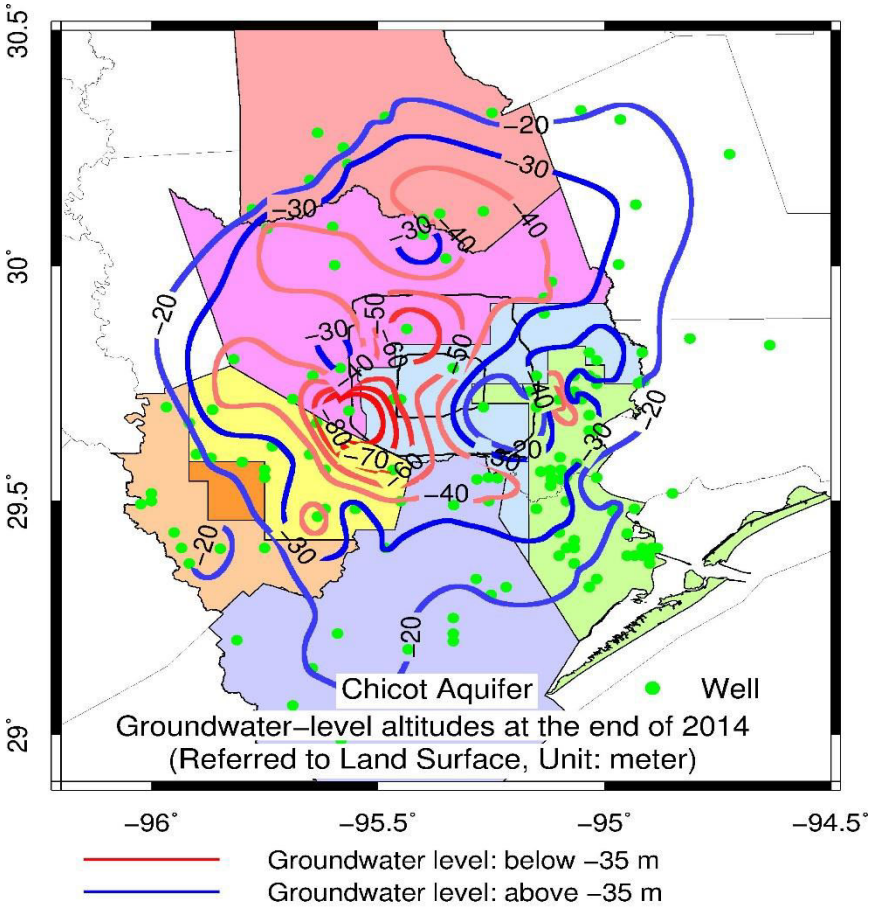


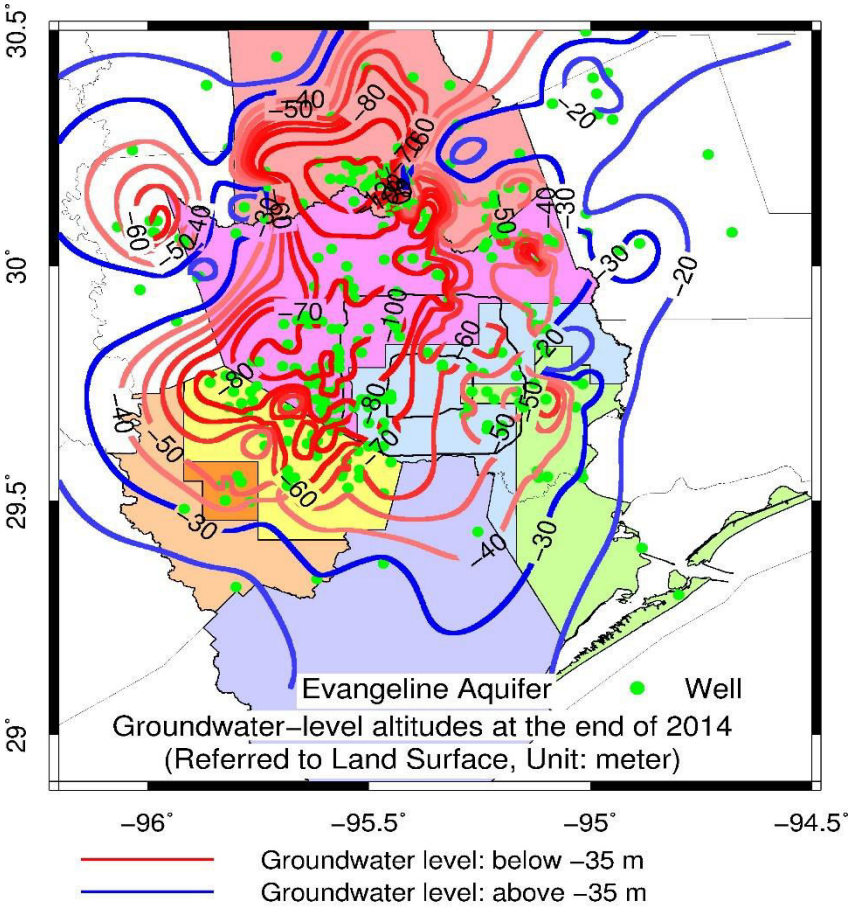
Groundwater Level Change (2005-2014)



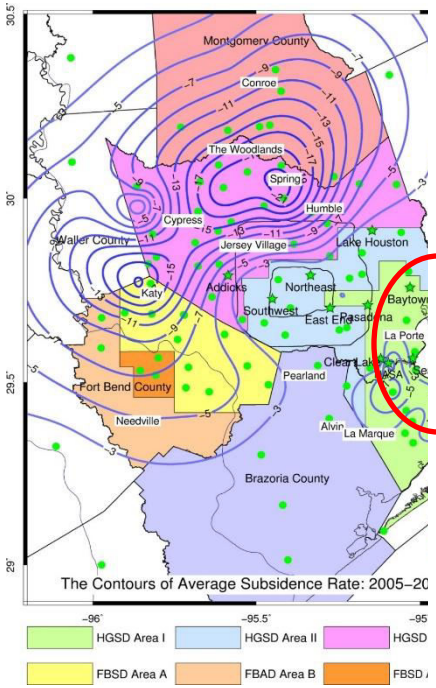


Preconsolidation Head: -35 m

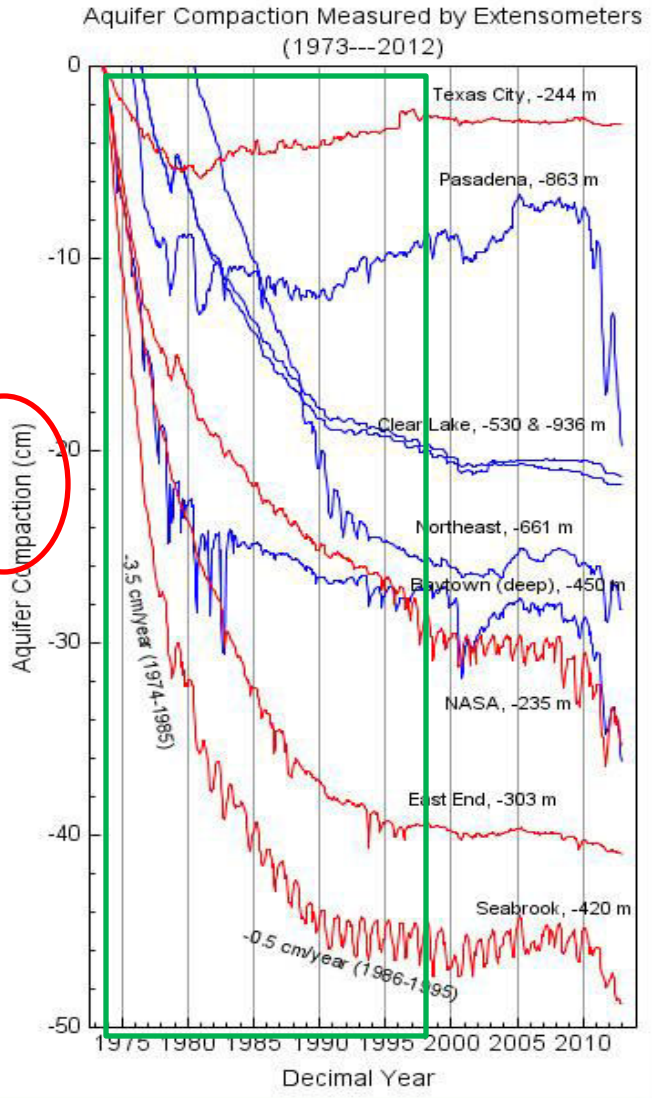


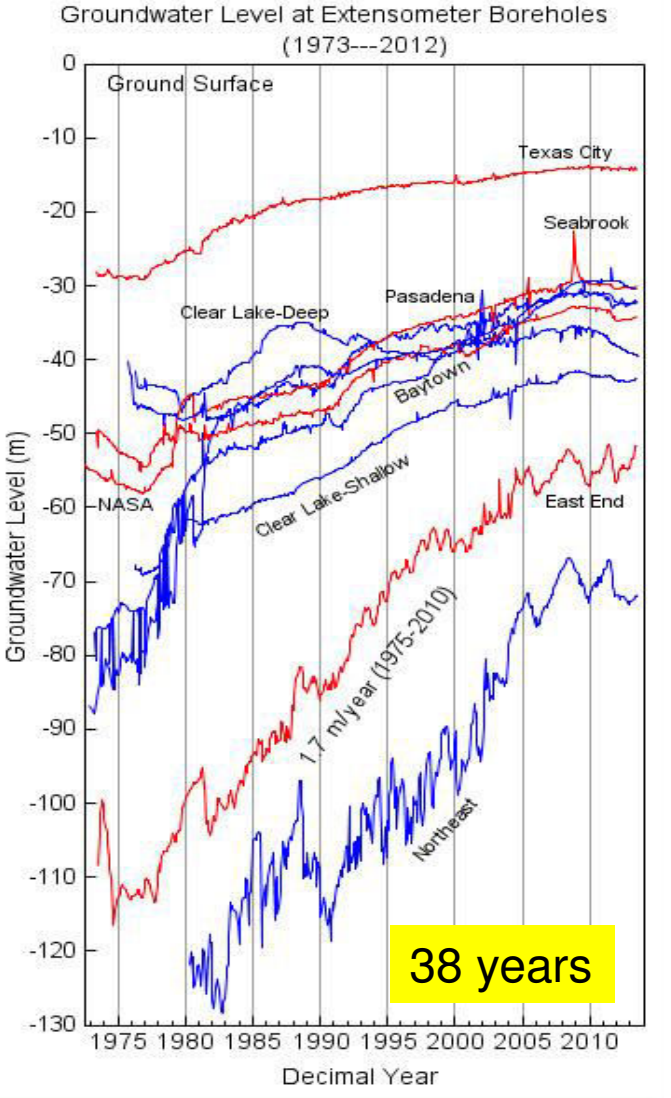


Kearns et al., 2015



1978-1998





38 years

Conclusion: It took 20 years (1978-1998) to halt the subsidence in the southeast part.

Summary

- The ground water and aquifer systems respond slowly to human actions. It took almost two decades (1980s and 1990s) to halt the subsidence in the south-east part of the Houston metropolitan area. Therefore, **a long-term perspective is needed to manage groundwater resources and control land subsidence.**

- The spatial and temporal variation of subsidence could be very considerable!
  subsidence=f(x,y,z,t)

- **T**here is no considerable deep-seated or fault-controlled subsidence in the Houston-Galveston area. Current aquifer compaction is limited to about -500m.

Thanks for attending the satellite conference!

2014 Spring GEOL4332: Geoscience Applications of GPS and LIDAR