A new earthquake monitoring method? Change in shear-wave anisotropy as a tool to monitor induced seismicity in Kansas and Oklahoma

Keith A. Nolte[1], George P. Tsoflias[1], Tandis S. Bidgoli[2], W. Lynn Watney[2]

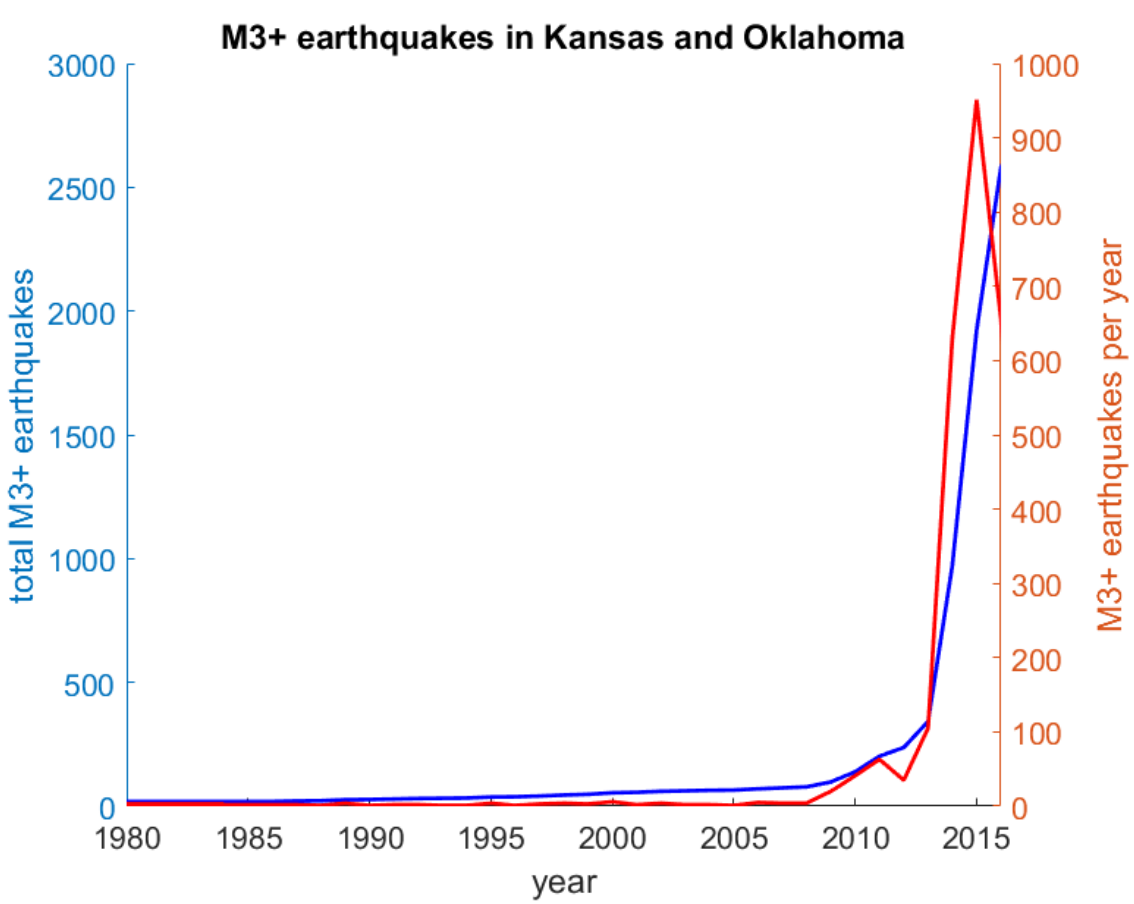
[1] The University of Kansas, Department of Geology

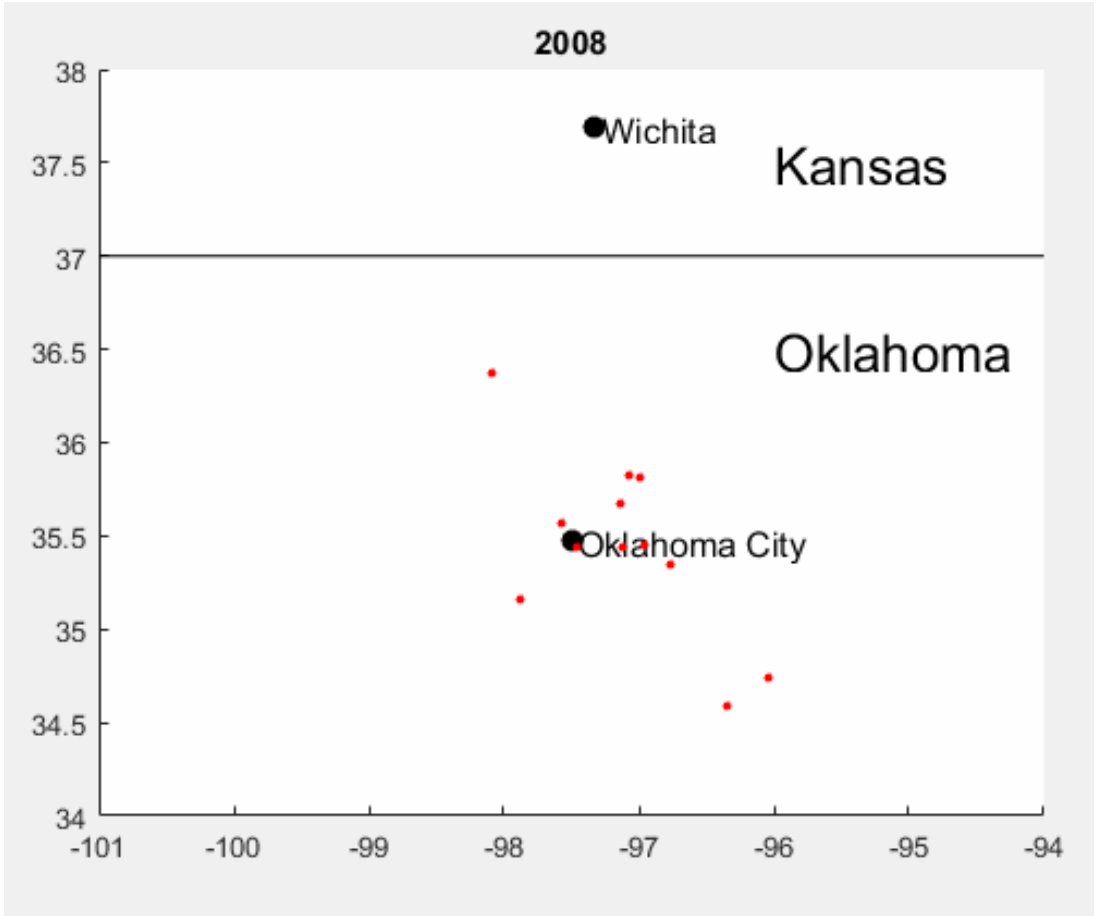
[2] The University of Kansas, Kansas Geological Survey

Overview

- Earthquakes in Oklahoma and Kansas
- Shear-wave anisotropy
- Shear-wave anisotropy observations in Sumner County, south-central KS
- Conclusions

Earthquakes in Oklahoma and Kansas

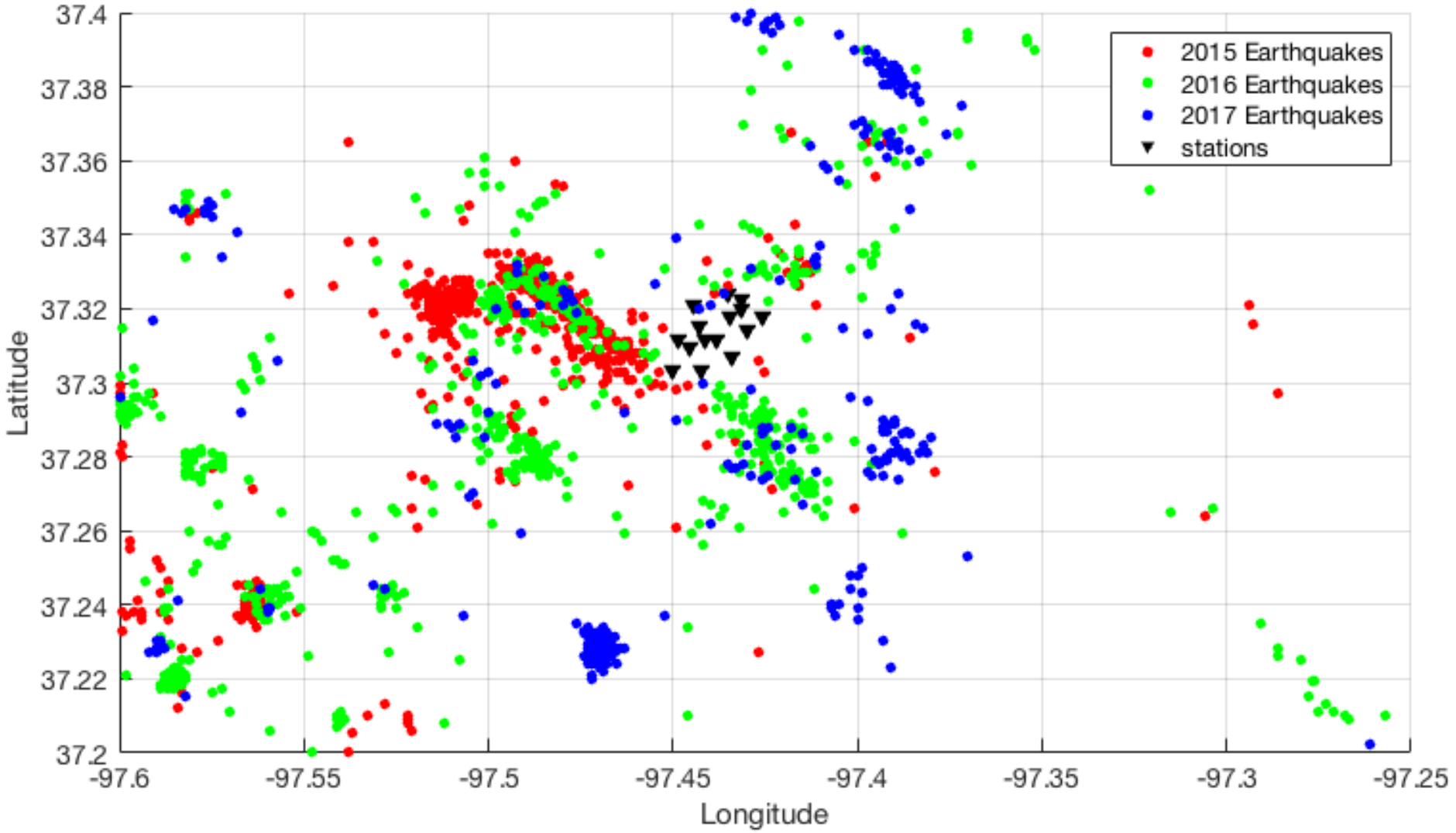




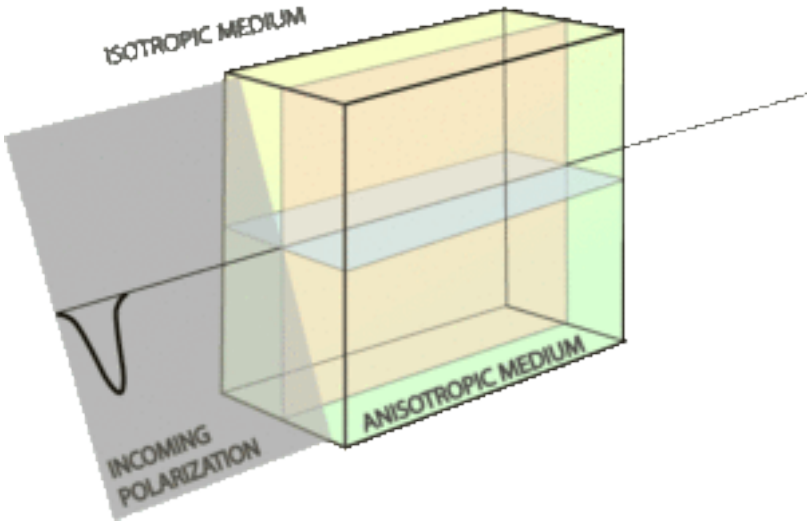
Data from USGS NEIC Catalog

Earthquakes near Wellington Network, Sumner County, south-central KS

- 2015 – 859 eqs
- 2016 – 1046 eqs
- 2017 – 1130 eqs (projected)



Shear-Wave Anisotropy



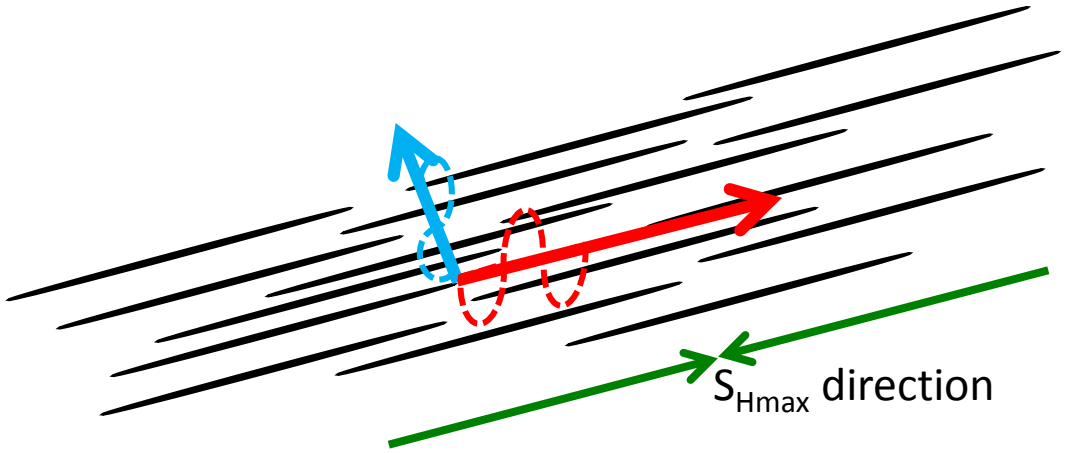
Garnero, 2017

- δt separation in time between fast and slow arrival
- ϕ azimuthal angle of fast arrival

Sources of Anisotropy

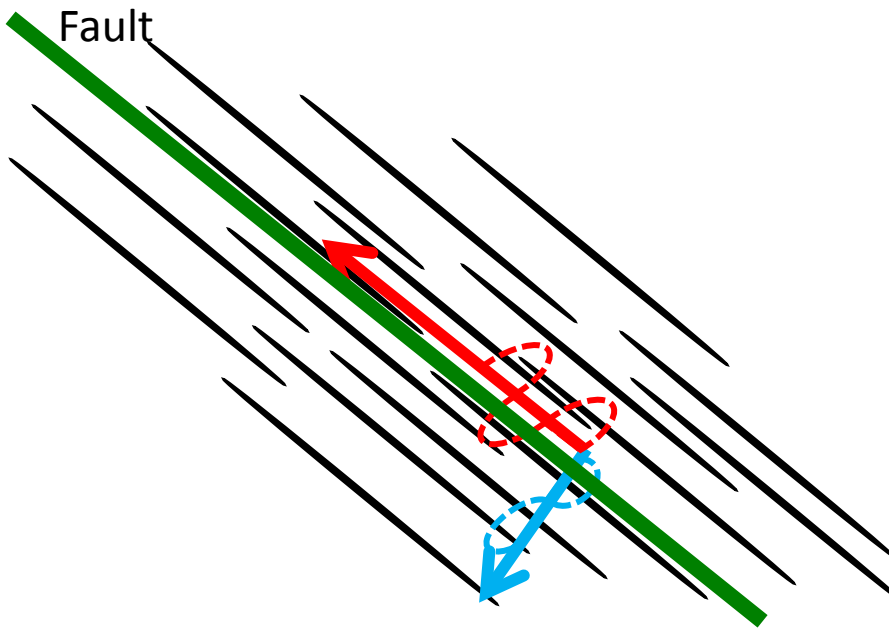
Stress-induced

- Fast S-wave aligns with S_{Hmax}
- Slow S-wave perpendicular to S_{Hmax}



Structure-controlled

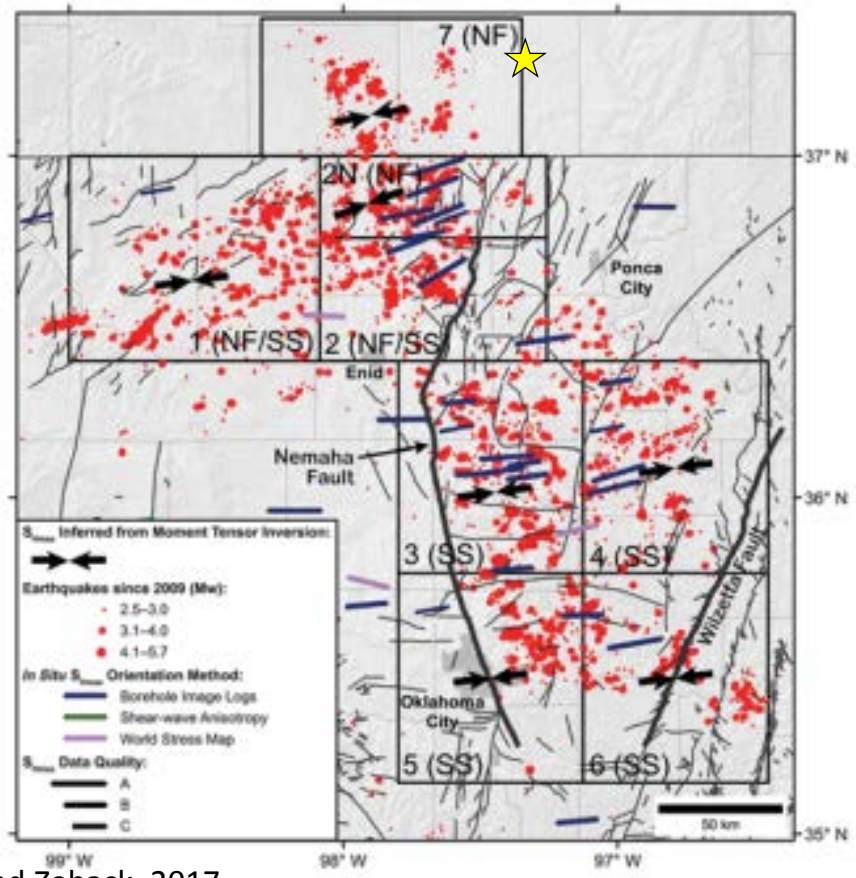
- Fast S-wave aligns with structure
- Slow S-wave perpendicular to structure



Anisotropy sources in Kansas

Stress-induced

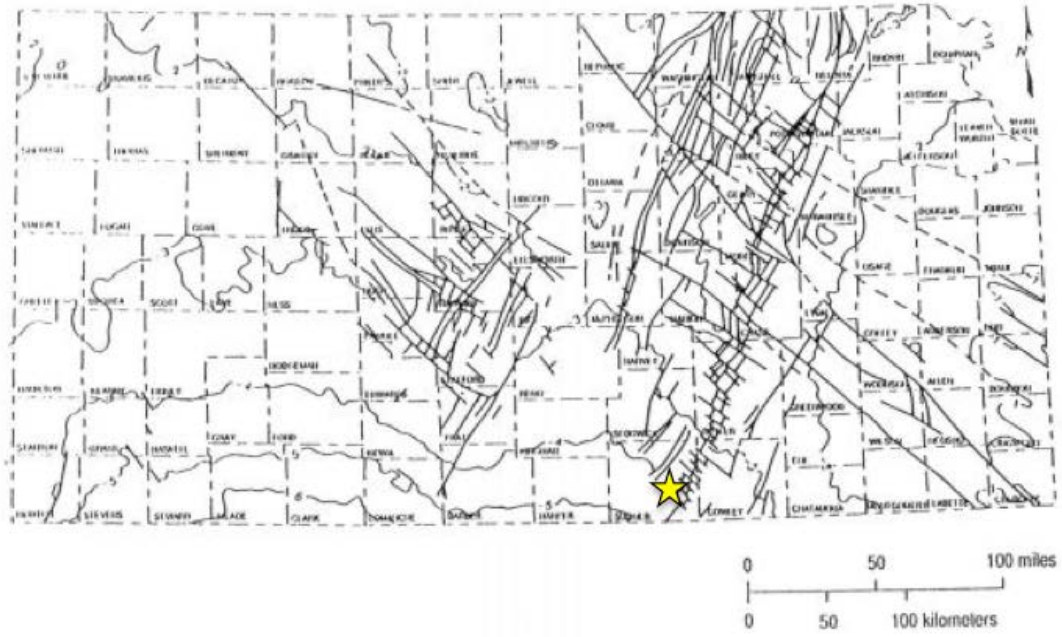
S_{hmax} ~80°



Alt III and Zoback, 2017

Structure-controlled

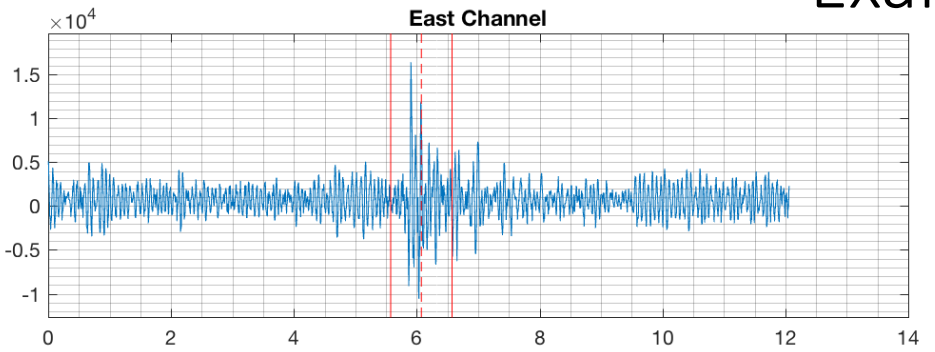
Major structure orientations at ~310° and ~30°

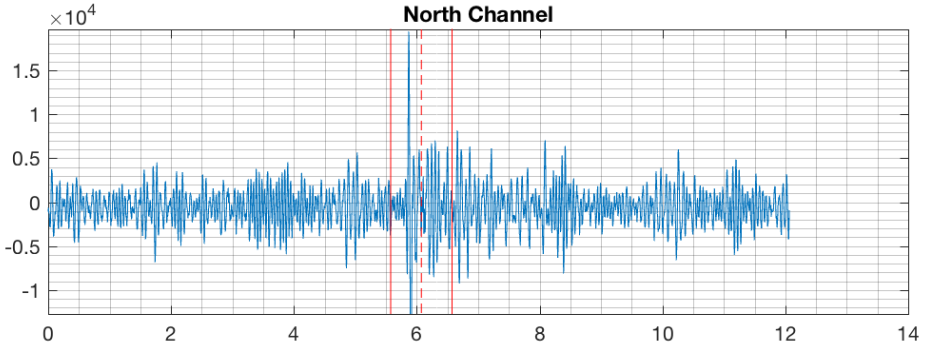


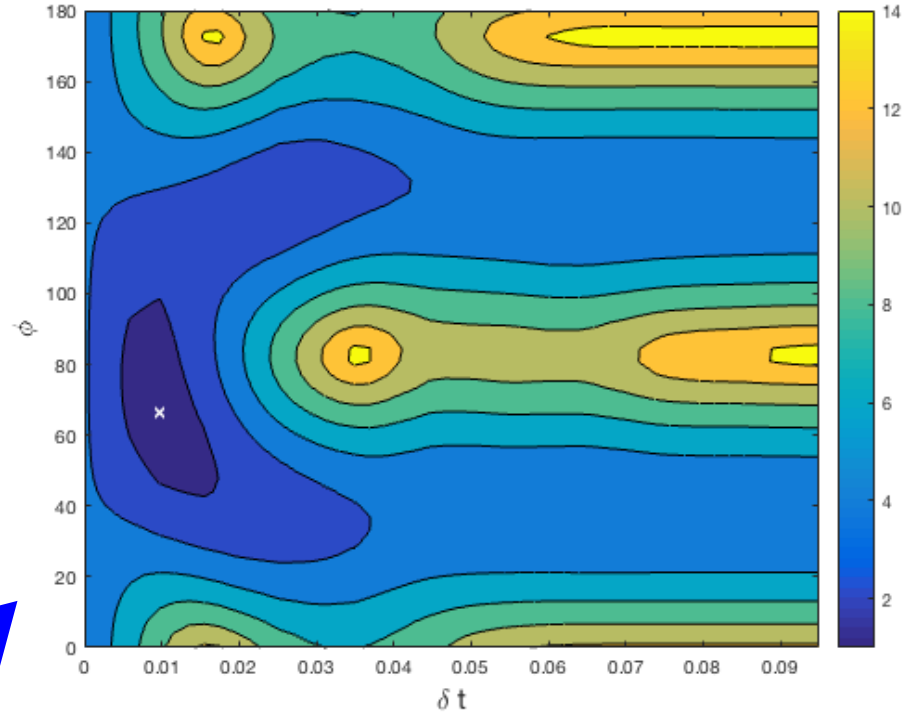
Baars, 1995

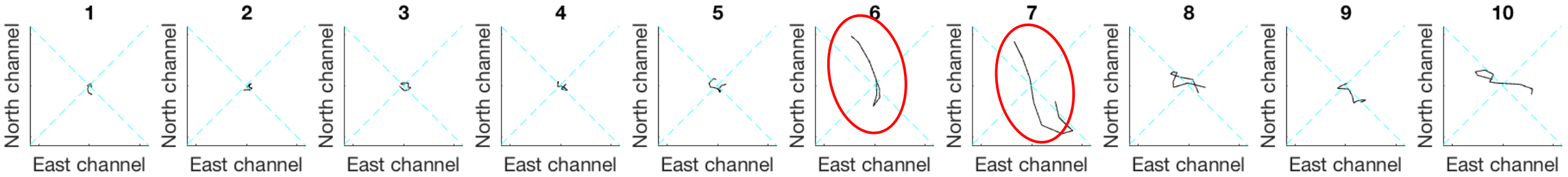
Calculating shear-wave parameters

Example from station WK01

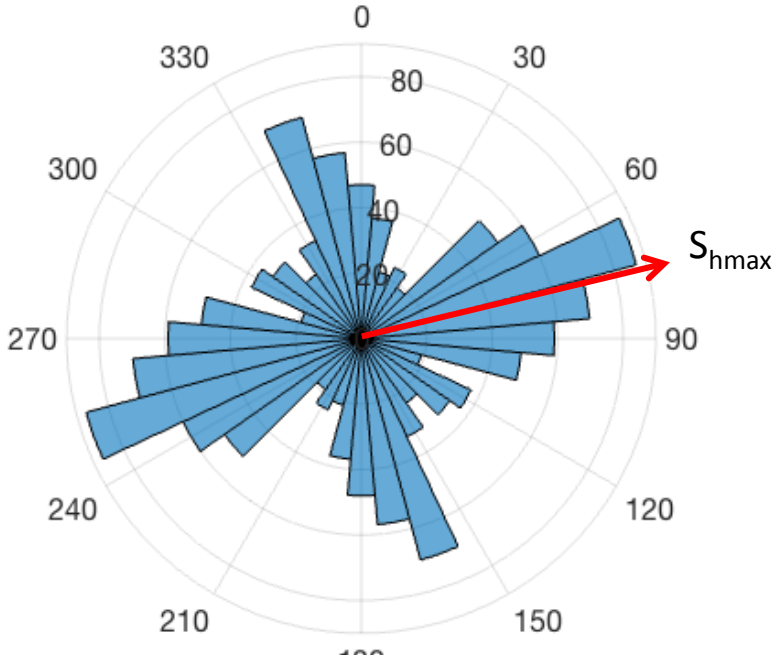




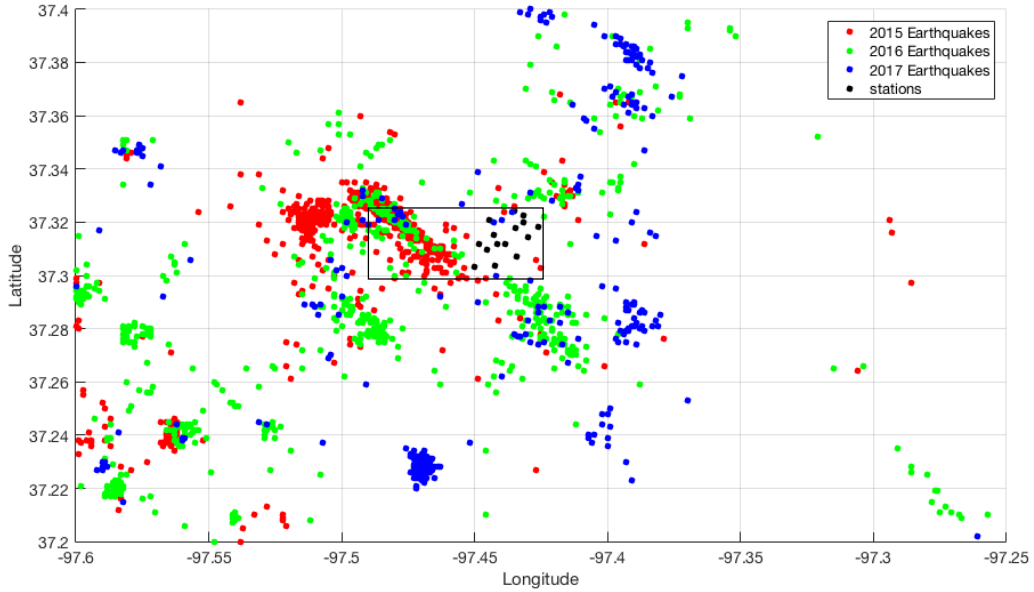


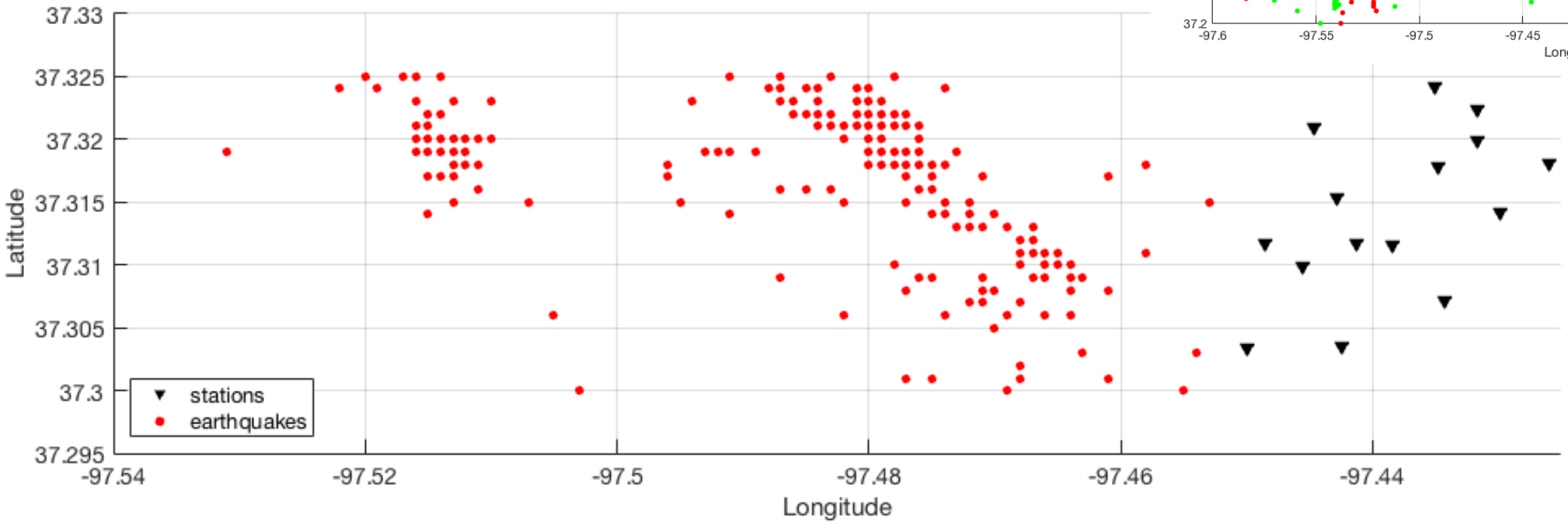


July-August 2015

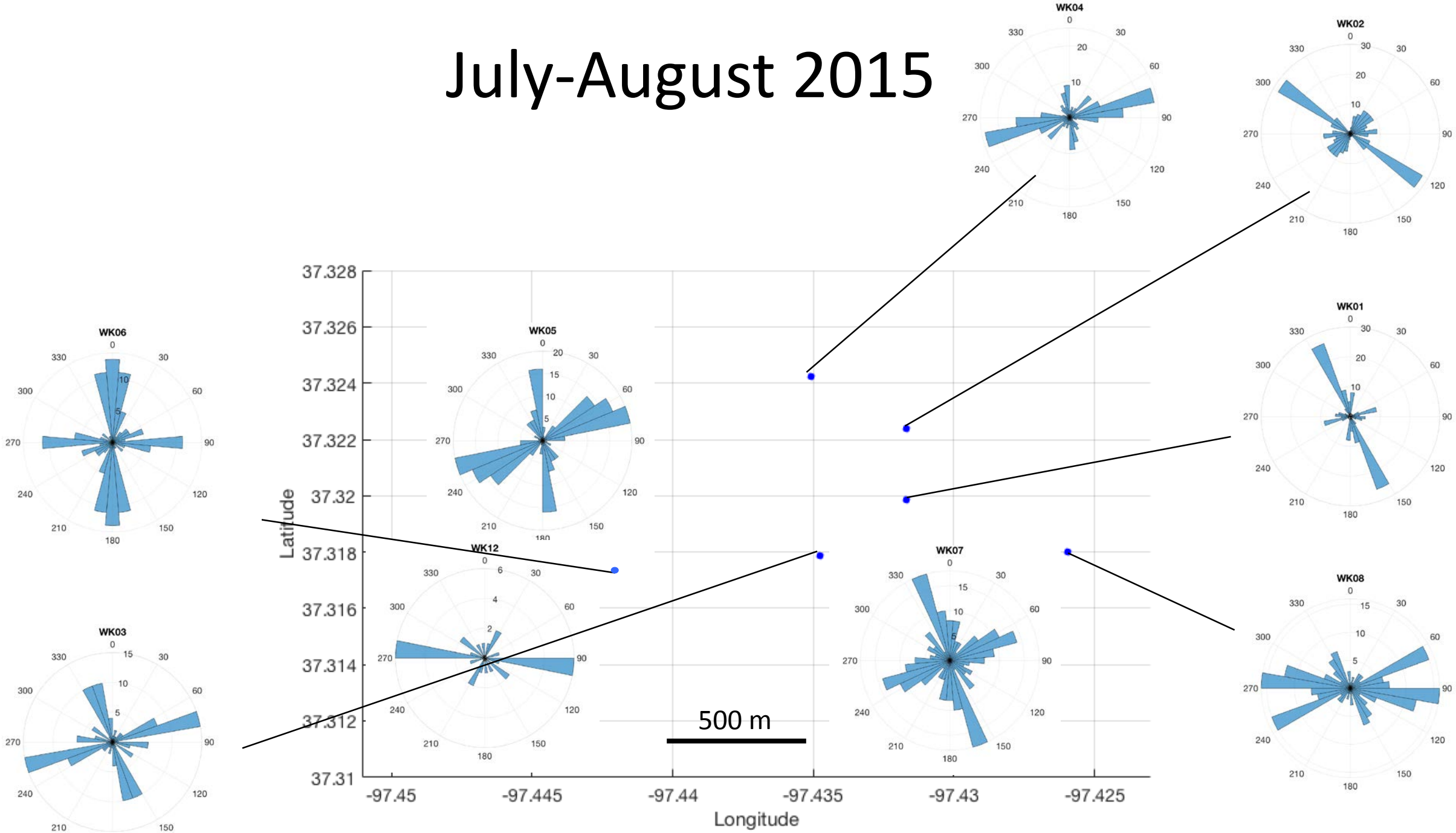


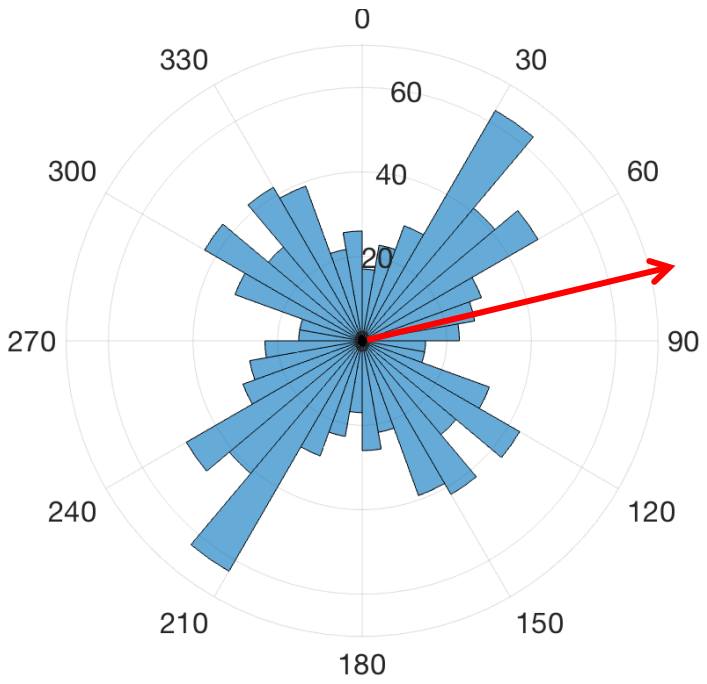
S_{hmax}





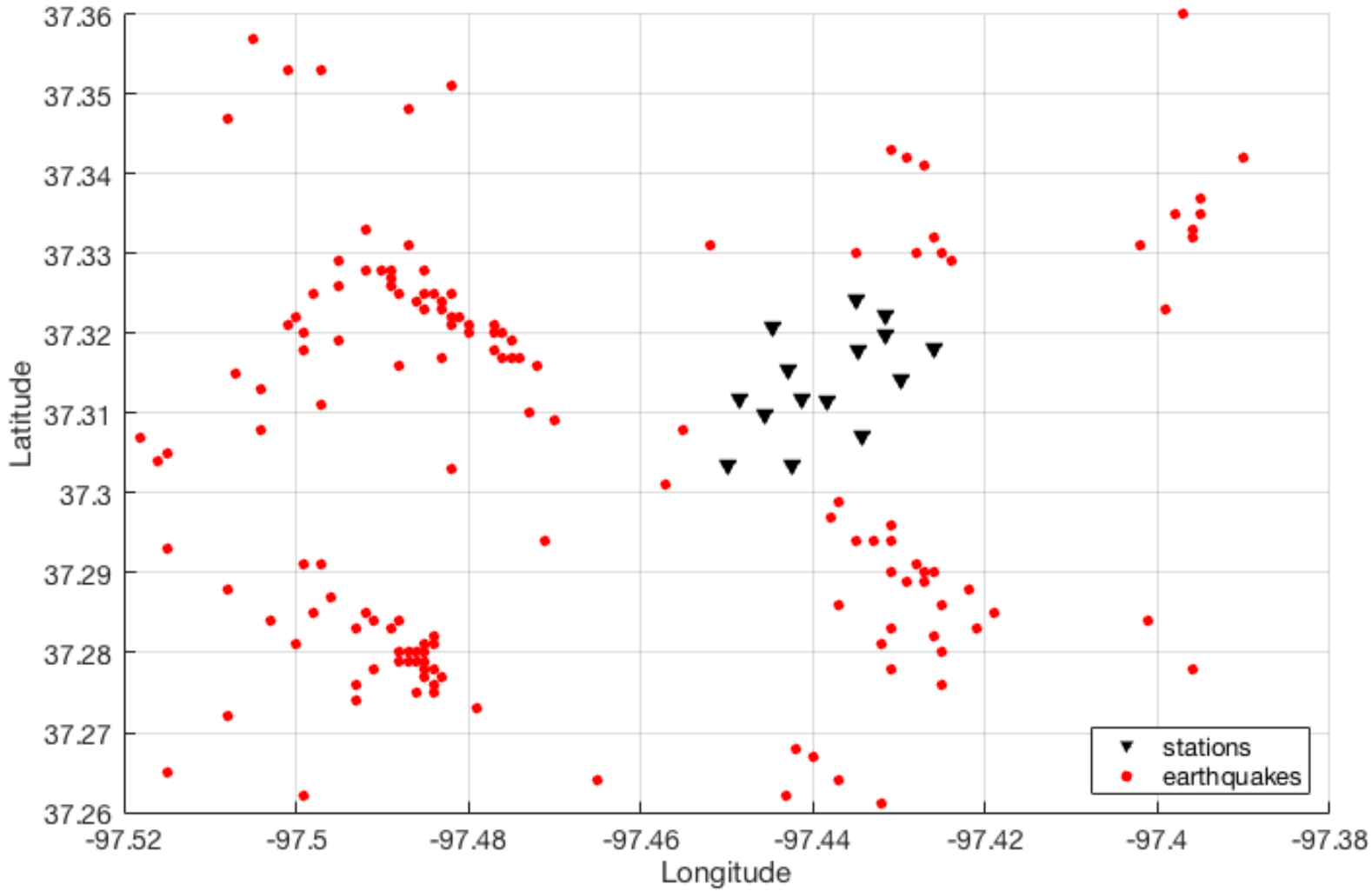
July-August 2015

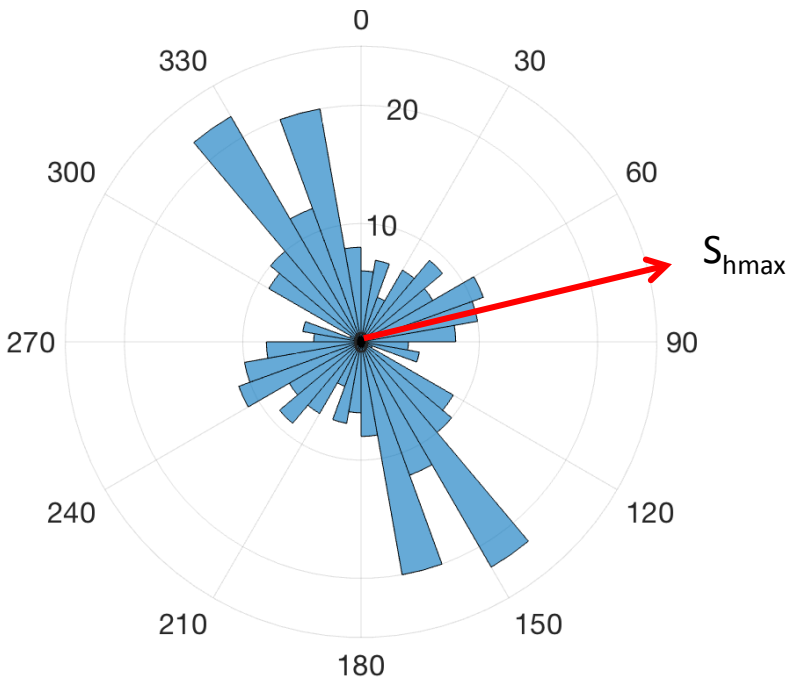




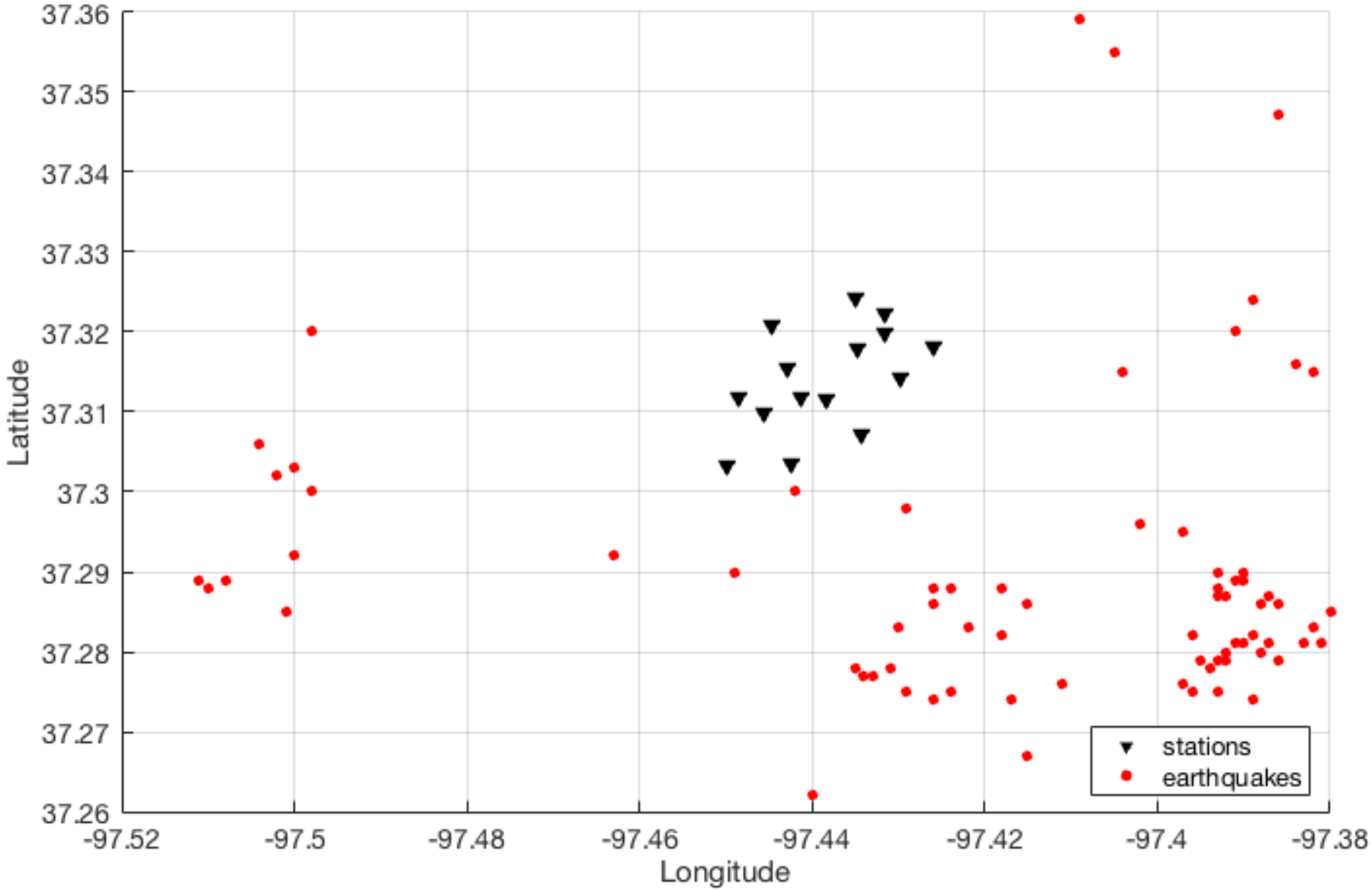
June-September 2016

S_{hma}



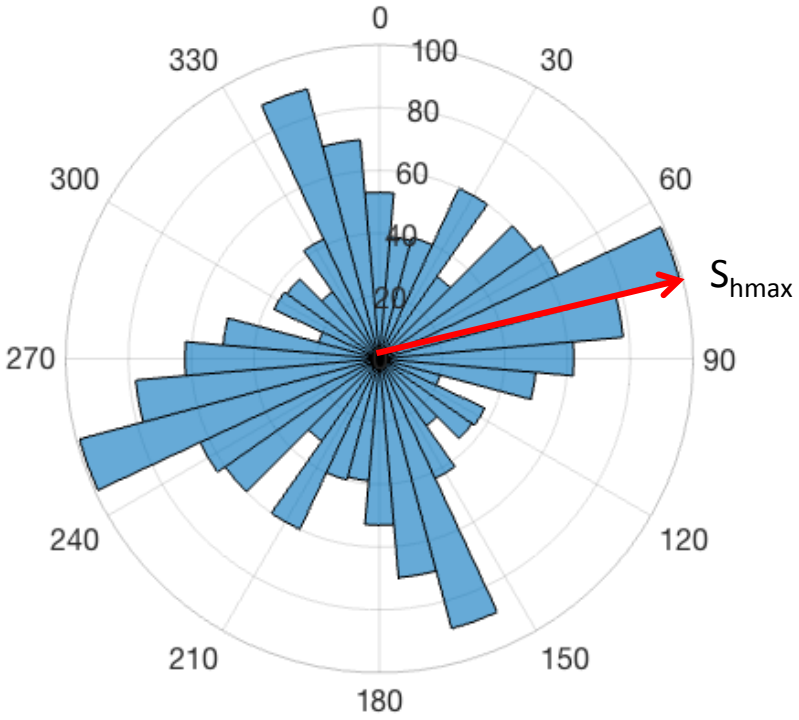


April-June 2017



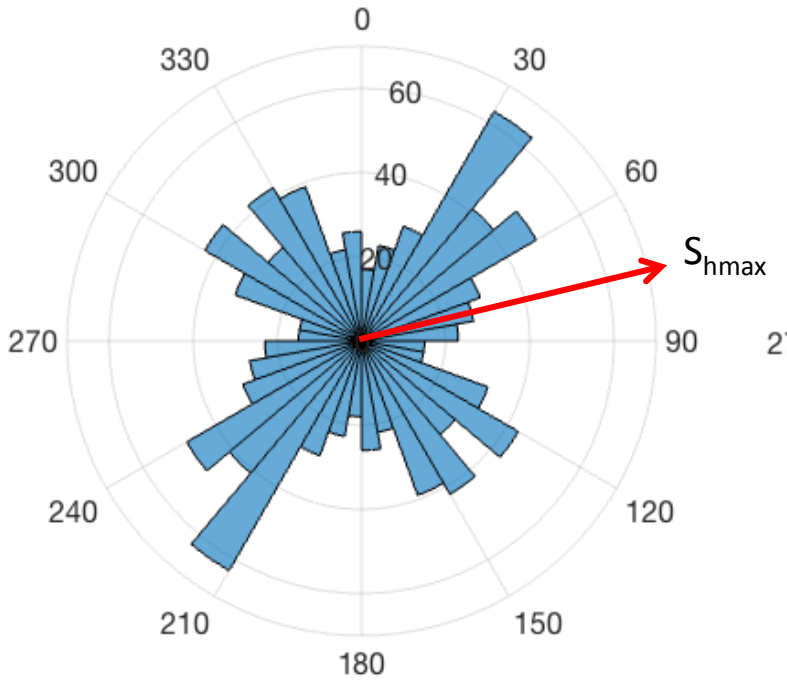
Year to year comparison

2015



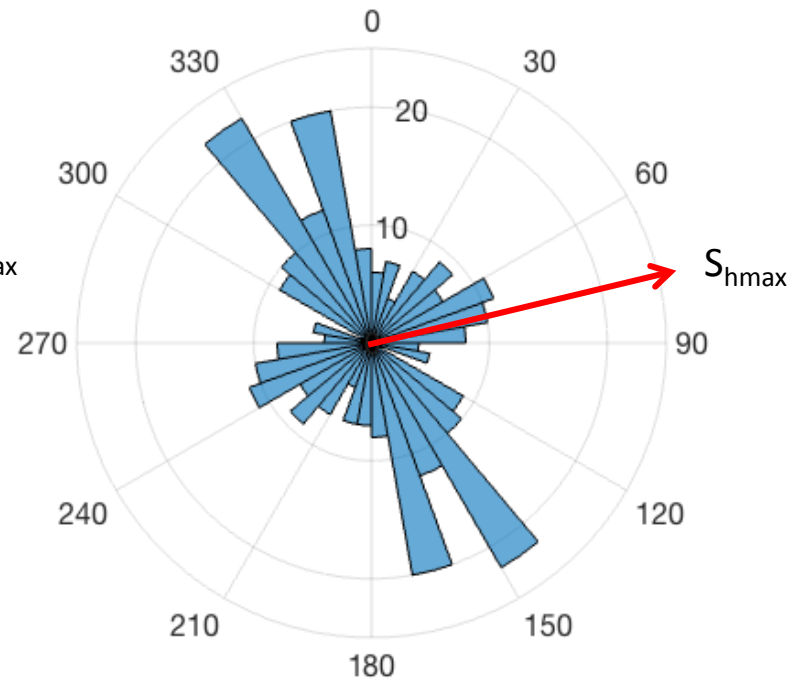
Combination of ϕ parallel and perpendicular to S_{hmax}

2016



ϕ neither parallel or perpendicular to S_{hmax}

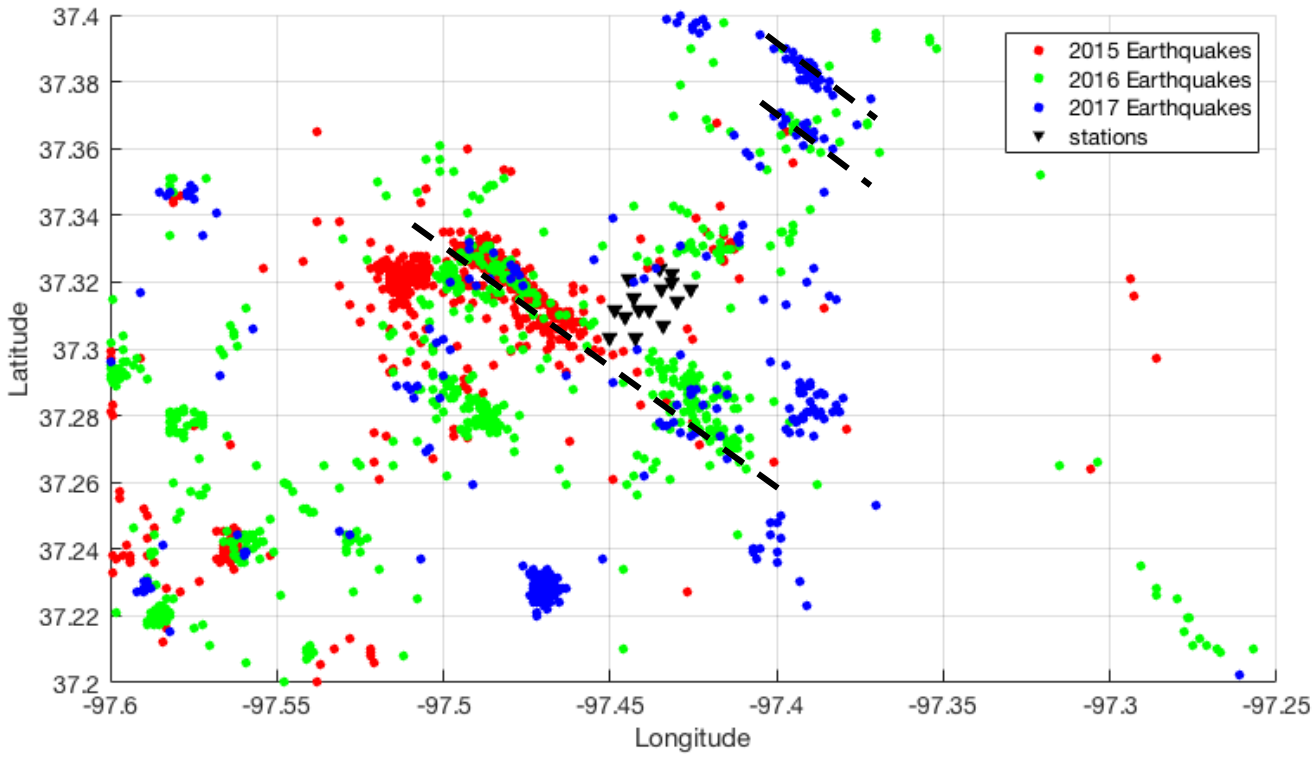
2017



Most ϕ perpendicular to S_{hmax}

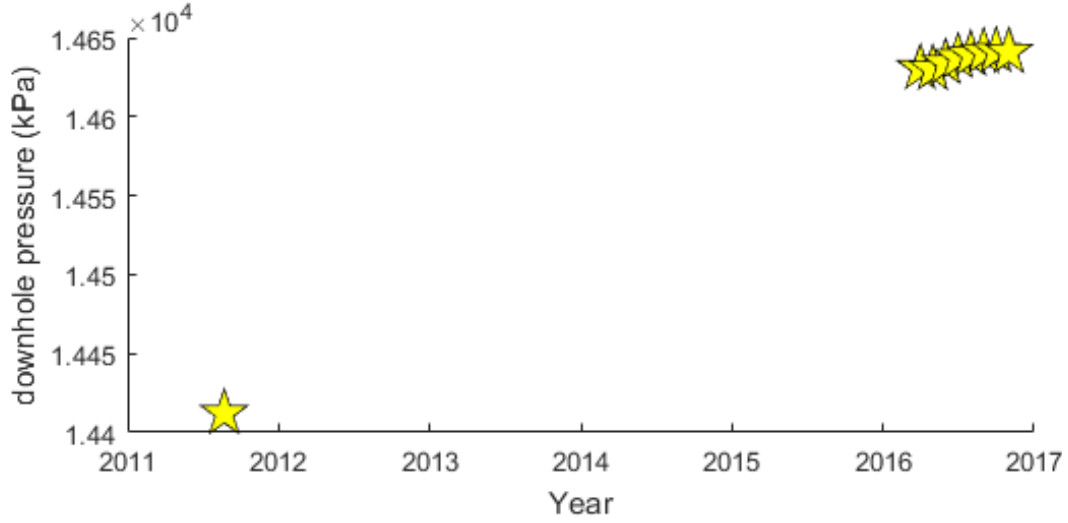
What can’t be causing the anisotropy change

- Tectonics
  - Midcontinent is not undergoing any tectonic change of this magnitude over this time period
- Structure
  - Some 2016 anisotropy lines up with structural trends but does not explain the change temporally
- Volcanism
  - There is currently no volcanism in Oklahoma and Kansas

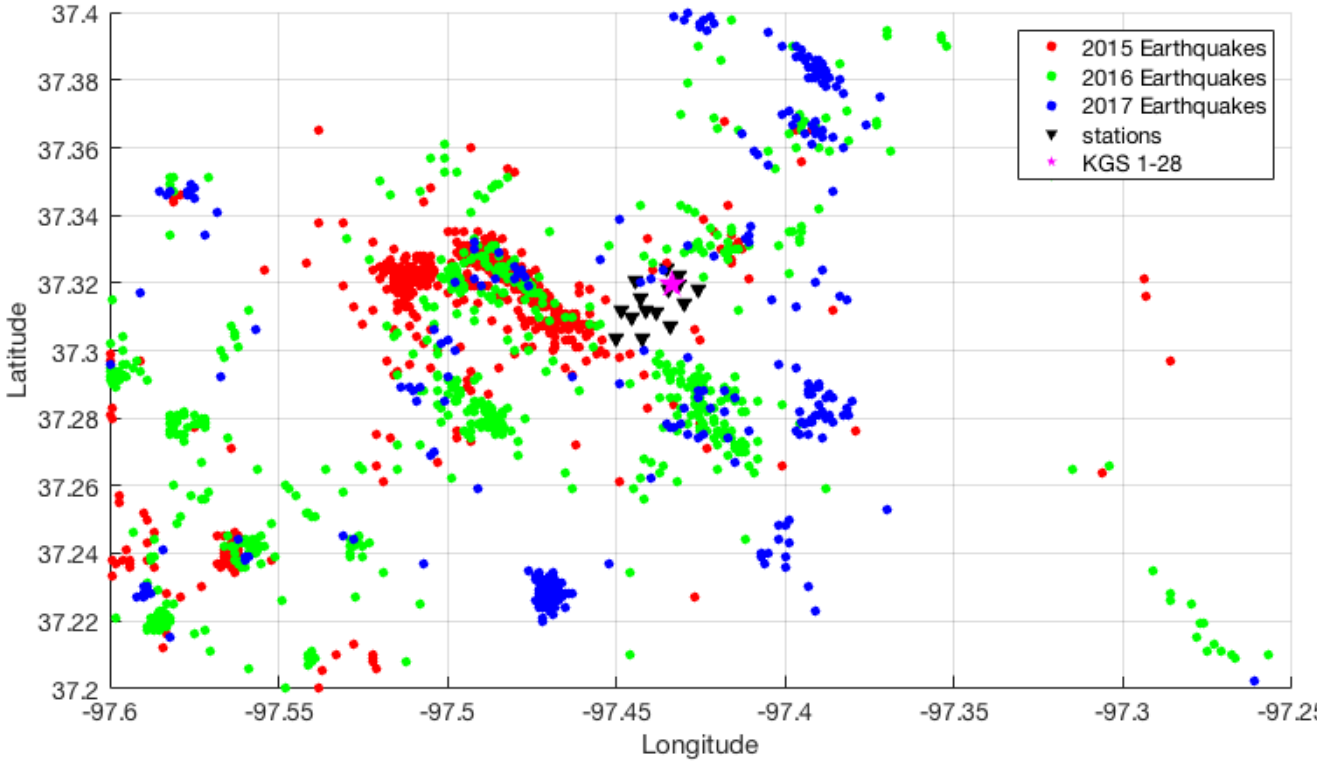


What is changing?

Bottom-hole pressure in KGS 1-28

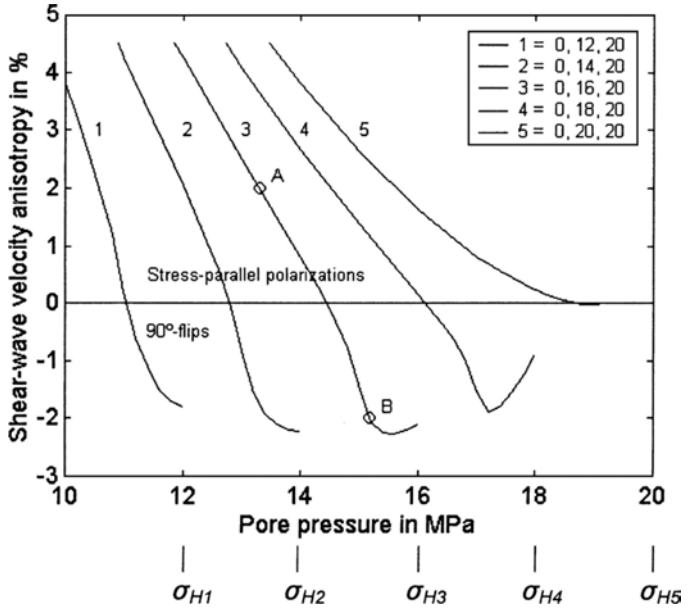


~200 kPa change (~30 psi) from 2011 to 2016

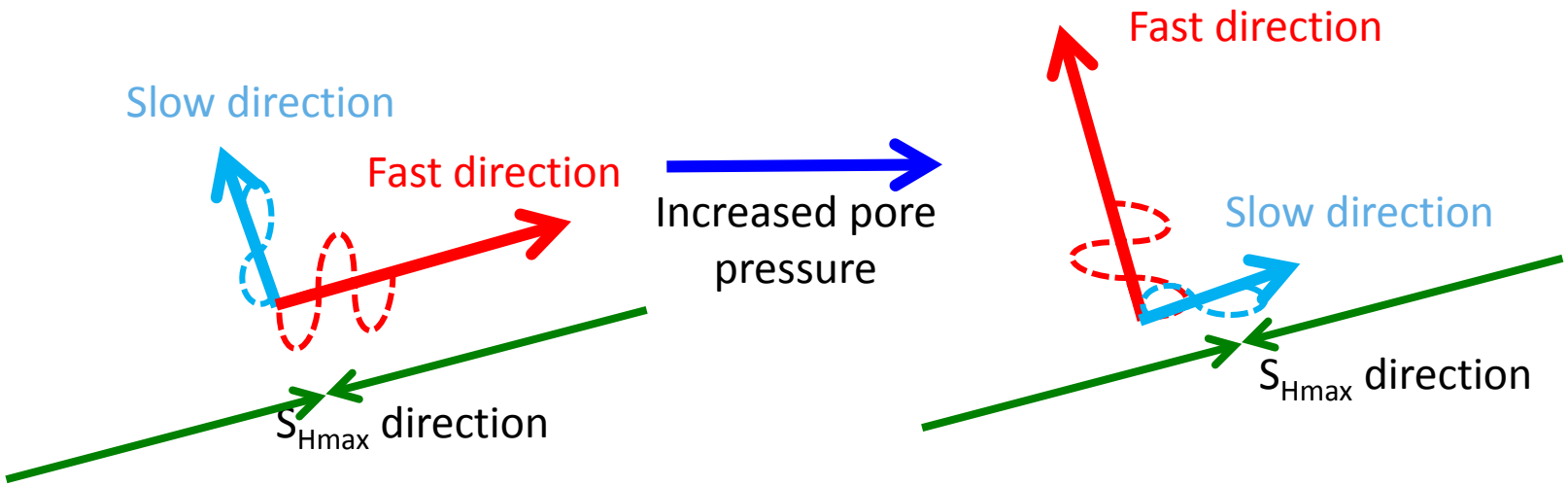


What could be causing the anisotropy change

- Changing pore fluid pressure
  - Evidence of change over the study period
  - Can force pre-existing fracture sets to open causing anisotropy



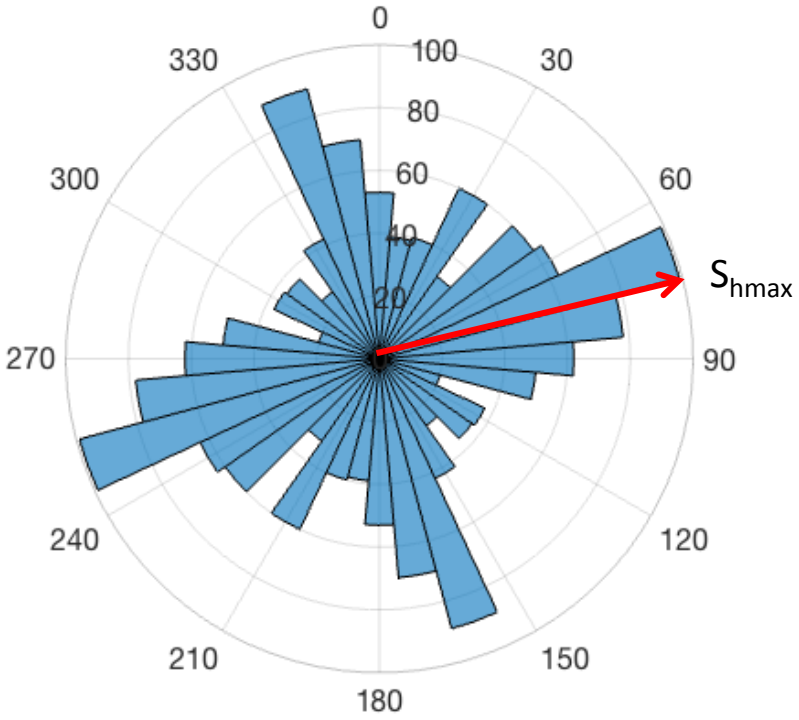
Crampin et al., 2002



Zatsepin and Crampin, 1997; Angerer et al., 2000, 2002; Crampin et al., 2002;

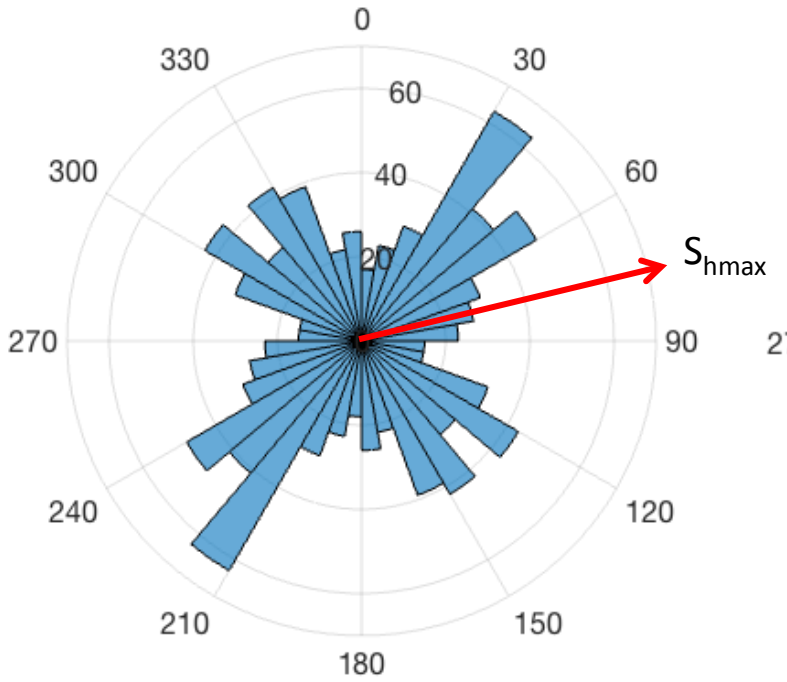
Year to year comparison

2015



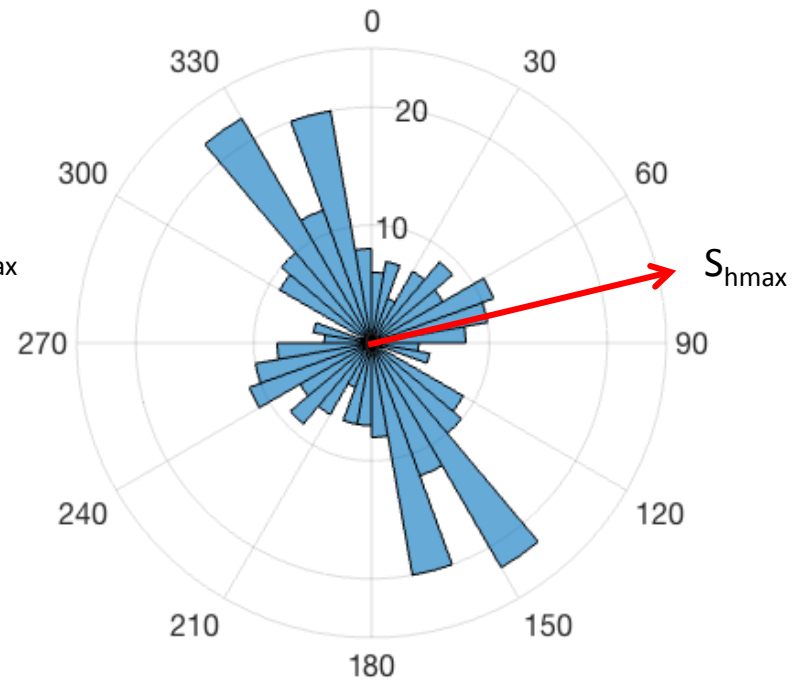
Combination of ϕ parallel and perpendicular to S_{hmax}

2016



ϕ neither parallel or perpendicular to S_{hmax}

2017



Most ϕ perpendicular to S_{hmax}

Conclusions

- Shear-wave anisotropy exhibits a temporal change
- Shear-wave anisotropy change is observed over the same time period of changing Arbuckle (injection interval) pore pressure
- No change in stresses or structure to cause temporal change in shear-wave anisotropy

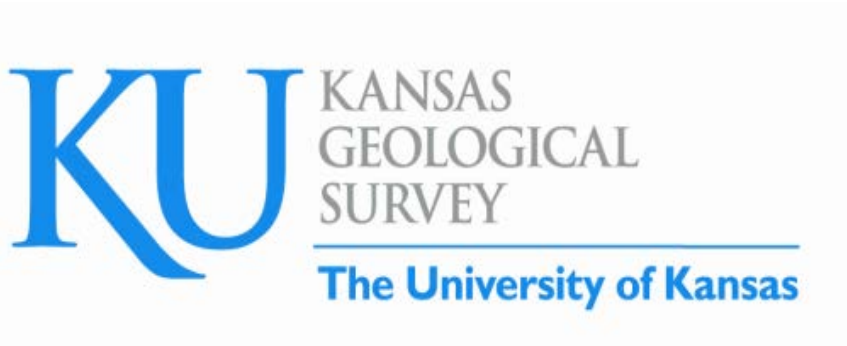
Future Work

- Expansion of shear-wave splitting catalog
- Shear-wave splitting tomography
- Test for spatial and temporal correlation between shear-wave anisotropy and downhole pressure data from regional injection wells
- Test methodology in other regions of injection-induced seismicity

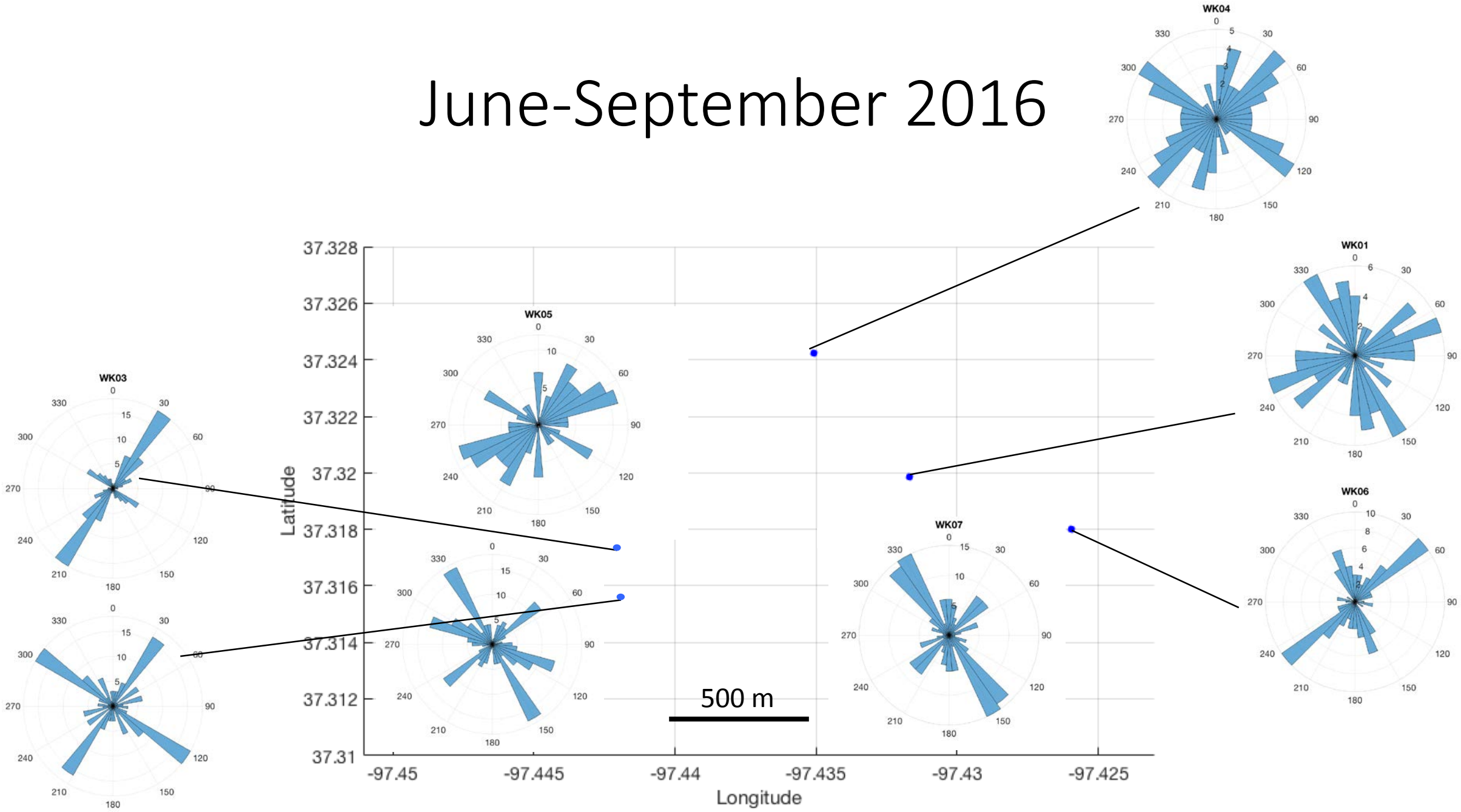
Acknowledgements

Grant No: DEFE0002056

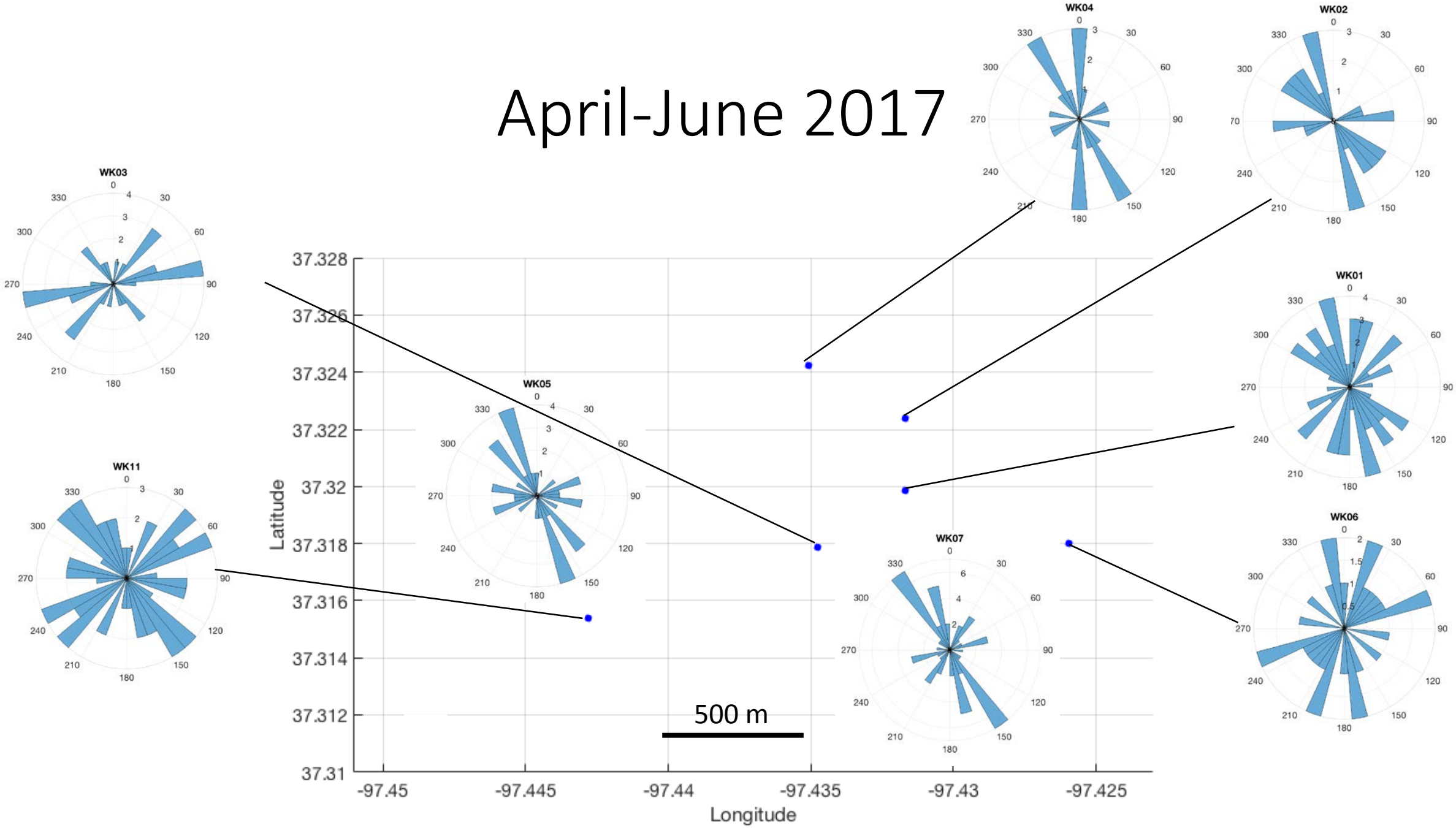
Grant No: INS0074816



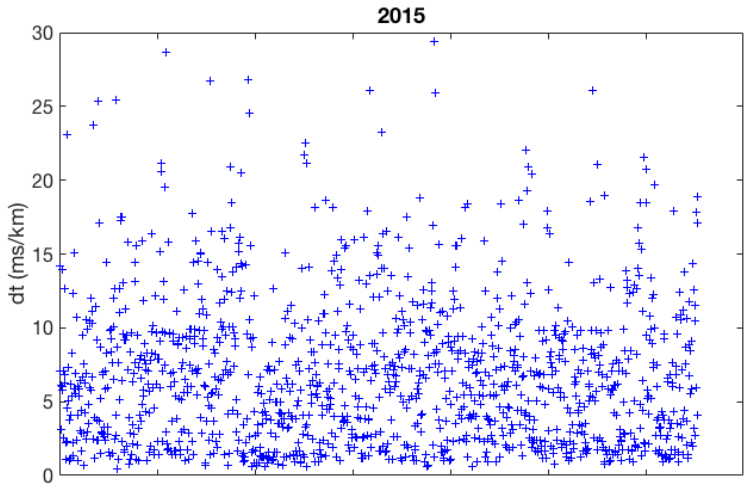
June-September 2016

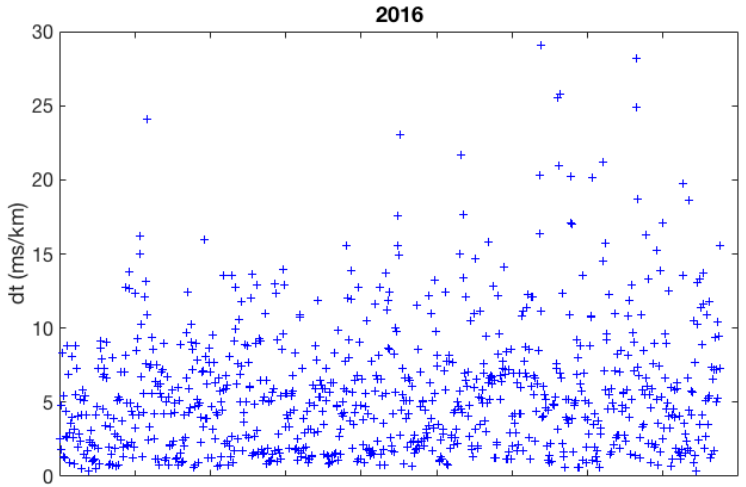


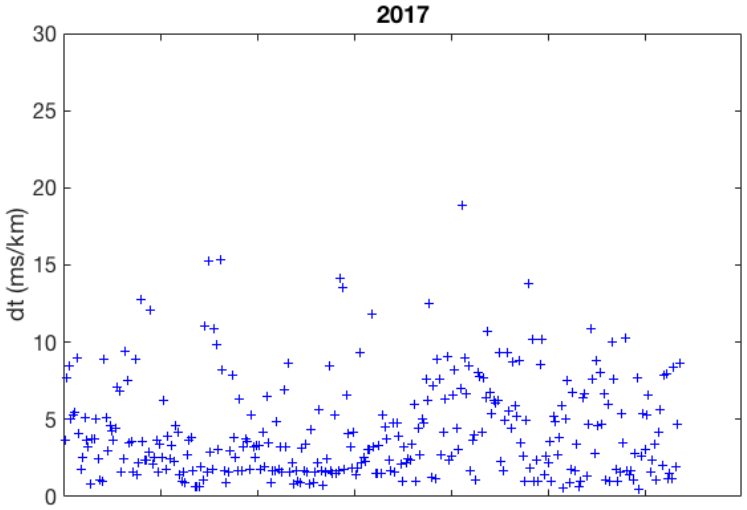
April-June 2017



Graphs of dt

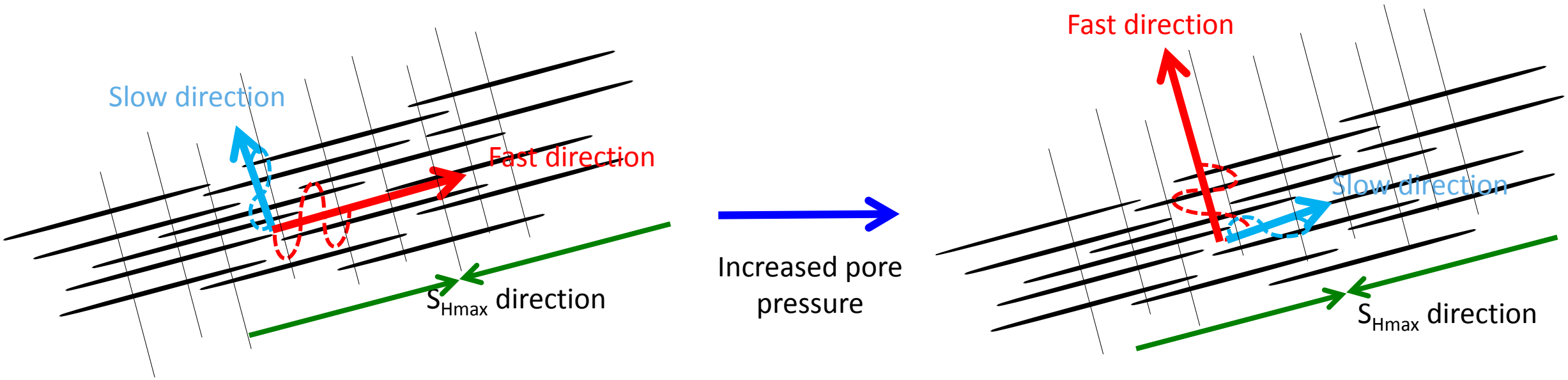

2015
dt (ms/km)
0
5
10
15
20
25
30


2016
dt (ms/km)
0
5
10
15
20
25
30


2017
dt (ms/km)
0
5
10
15
20
25
30

What could be causing the anisotropy change

- Changing pore fluid pressure
  - Evidence of change over the study period
  - Can force pre-existing fracture sets to open causing anisotropy



Zatsepin and Crampin, 1997; Angerer et al., 2000, 2002; Crampin et al., 2002;