Real-time Earthquake Detection System at the Alaska Earthquake Center

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AEC mission and historical perspective

- Regional seismic network established in Alaska in late 60s- early 70s, in the wake of the 1964 M9.2 Great Alaska earthquake.

- AEIC formally established in 1989 to:
  - Assess seismic hazards for Alaska
  - Collect, analyze and archive seismic data
  - Provide information and assistance to State and local agencies, public and research community

- We are not alone and work with many State and Federal partners.

Current state

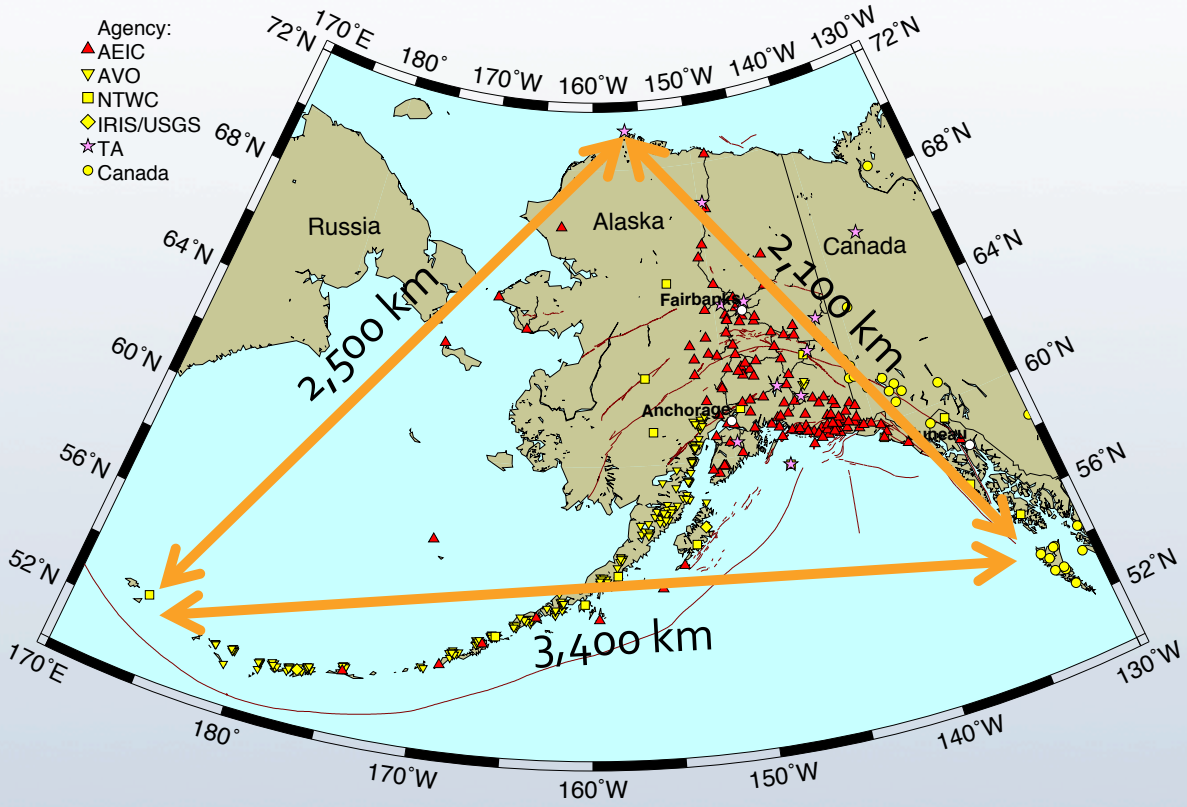
- We are members of ANSS – Advanced National Seismic System. One of our key responsibilities is real time earthquake reporting for Alaska region.
- We collect, analyze and archive data from about 400 seismic sites in the State, and also from our neighbors Canada and Russia and Global Seismic Network.
- We locate about 30,000 local and regional earthquakes per year.
- We are responsible for maintenance of ~200 seismic sites.
- We provide seismic monitoring of the Trans-Alaska Oil Pipeline, and hydro-electric dams.
- We participate in the Tsunami Hazard program by producing tsunami inundation maps for coastal communities in the State.
- We currently have 20 staff, faculty and postdoc positions.

Factors that play into real-time earthquake monitoring

- Processing system: We run Antelope (Boulder Real Time Technologies, Inc.) based systems for real-time and post-processing.

- Challenges:
  - Need to adhere to reporting standards set by ANSS (Latency of earthquake reporting, accuracy of locations and magnitudes).
  - Inhomogeneous station distribution.
  - Inhomogeneous seismicity distribution, with earthquake depths ranging down to 250 km.
  - Quality of waveforms data, data outages.

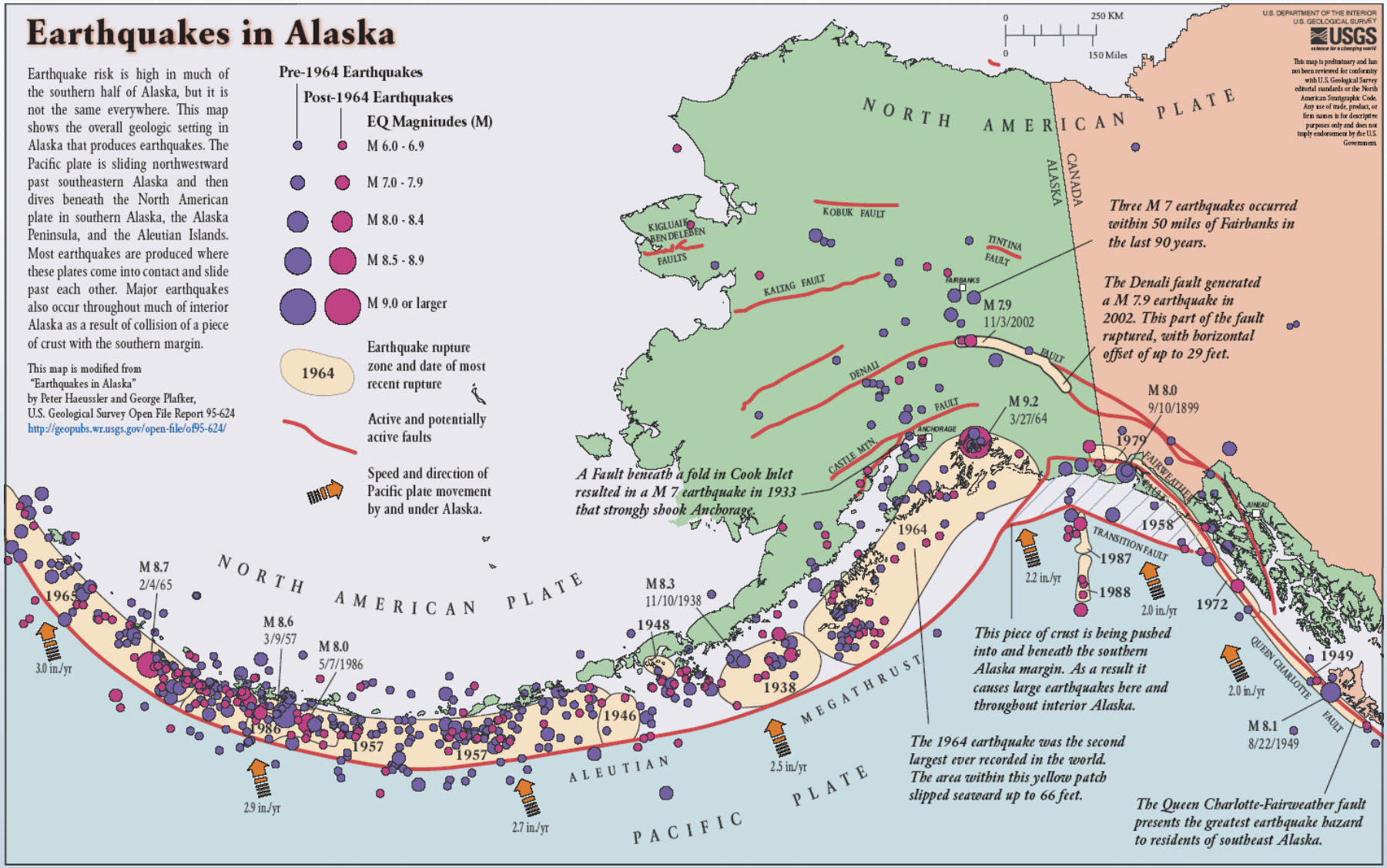
Alaska regional seismic network



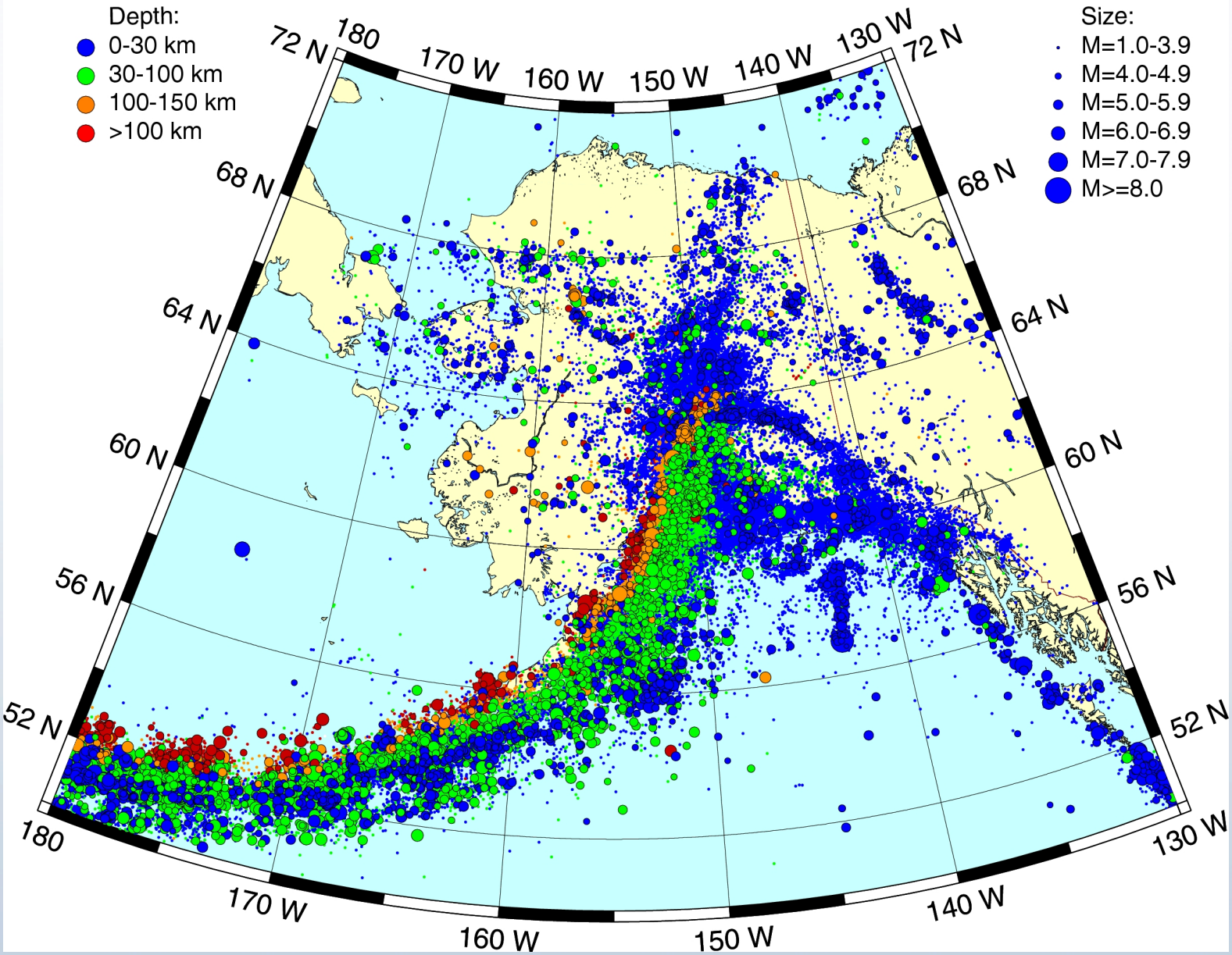
- 400+ stations
- Regional network:
  - 1/3 is Earthquake Center (AK)
  - 1/2 is Volcano Observatory (AV)
  - Remaining 1/5 is Tsunami Warning Center (AT), GSN (UU/UI), USGS (US), and TA combined

- 2/3 of stations are digital broadband, ~1/3 of stations are short period analog

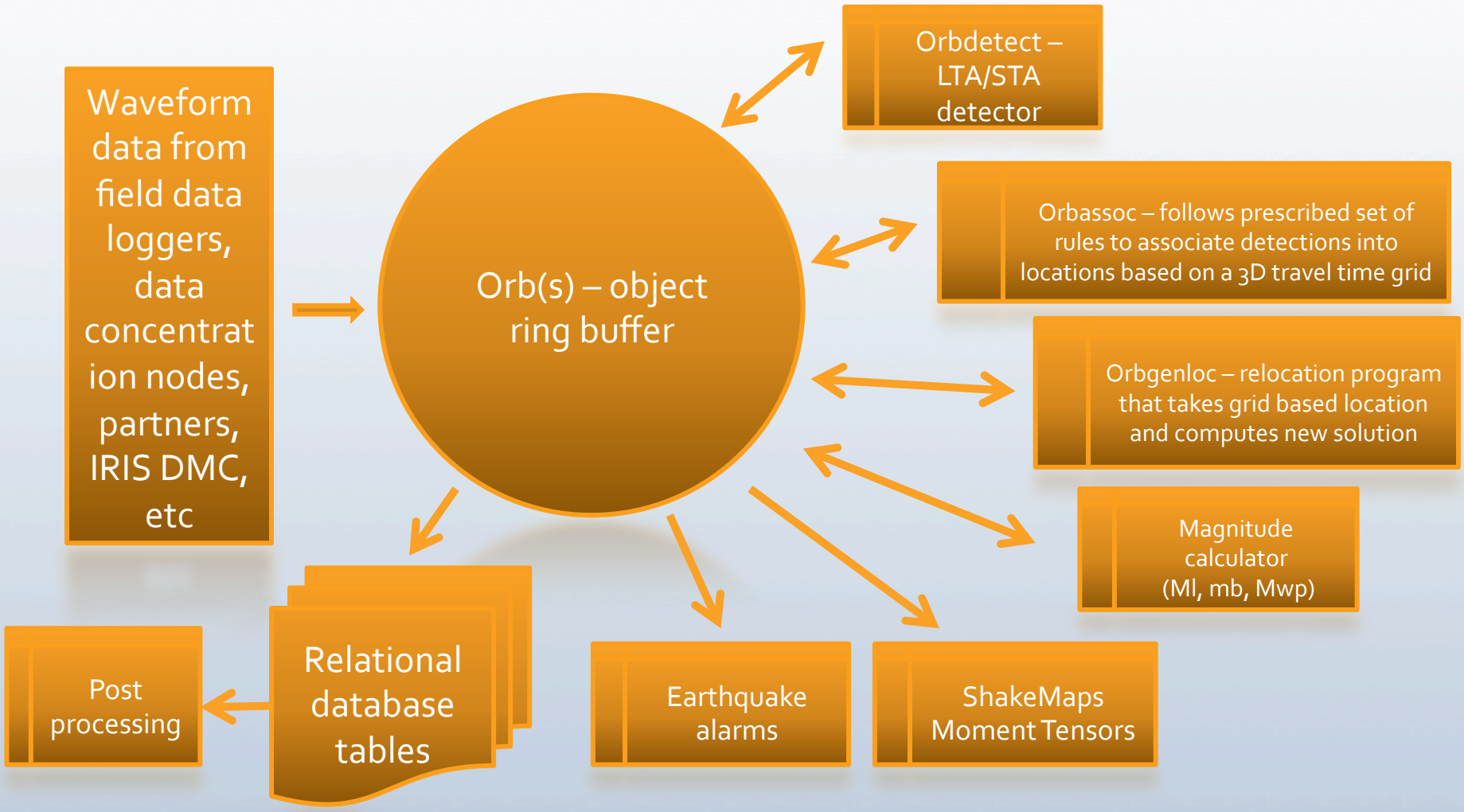
Tectonic of Alaska



Earthquakes in Alaska 1970-2009



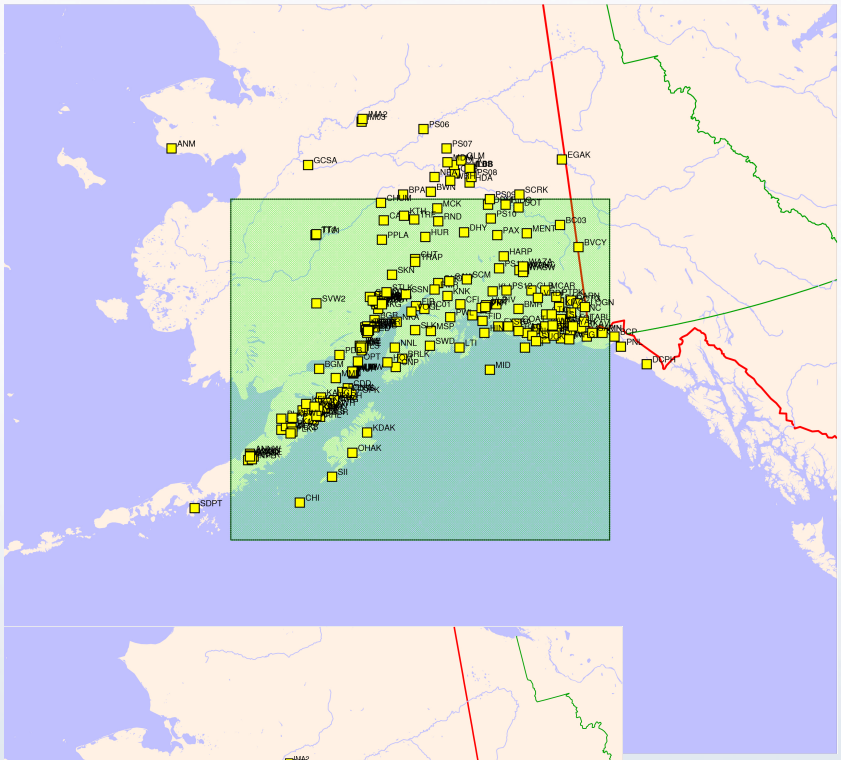
Real-time data flow and processing

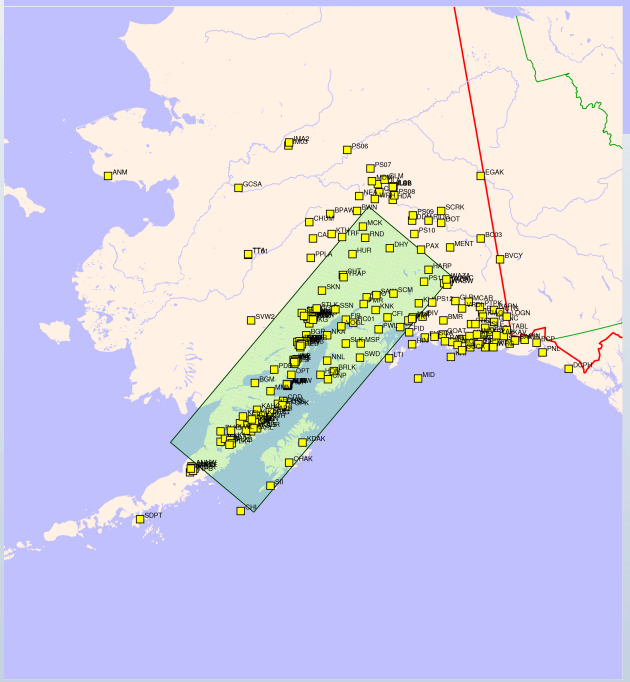


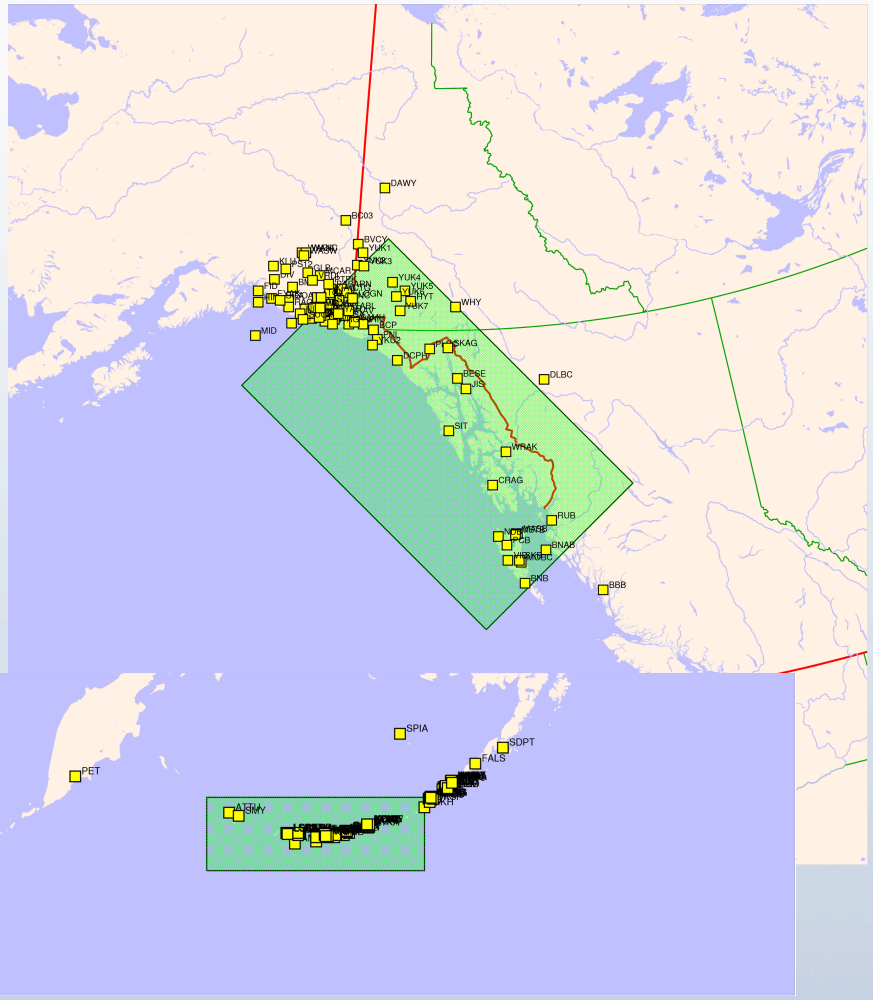
Event associations

- Regional travel-time grids are created to match natural distribution of seismicity across the monitoring region.
- We detect (associate) teleseismic events with utele grid using all regional and subset of global stations.
- Examples of parameters that can be tuned (*orbdetect.pf* and *orbassoc.pf*):
  - Clustering time window for concurring arrivals (depends on network aperture),
  - Number of arrivals within certain distance of epicenter (depends on station density),
  - Frequency of solution updates (through wall clock or number of detections),
  - Rules for when arrivals can be treated as P or S,
  - Upper limits on travel-time residuals.
- We run tests with different sets of parameters and choose those that produce minimal number of mis-associations for operational mode.

Regional travel-time grids





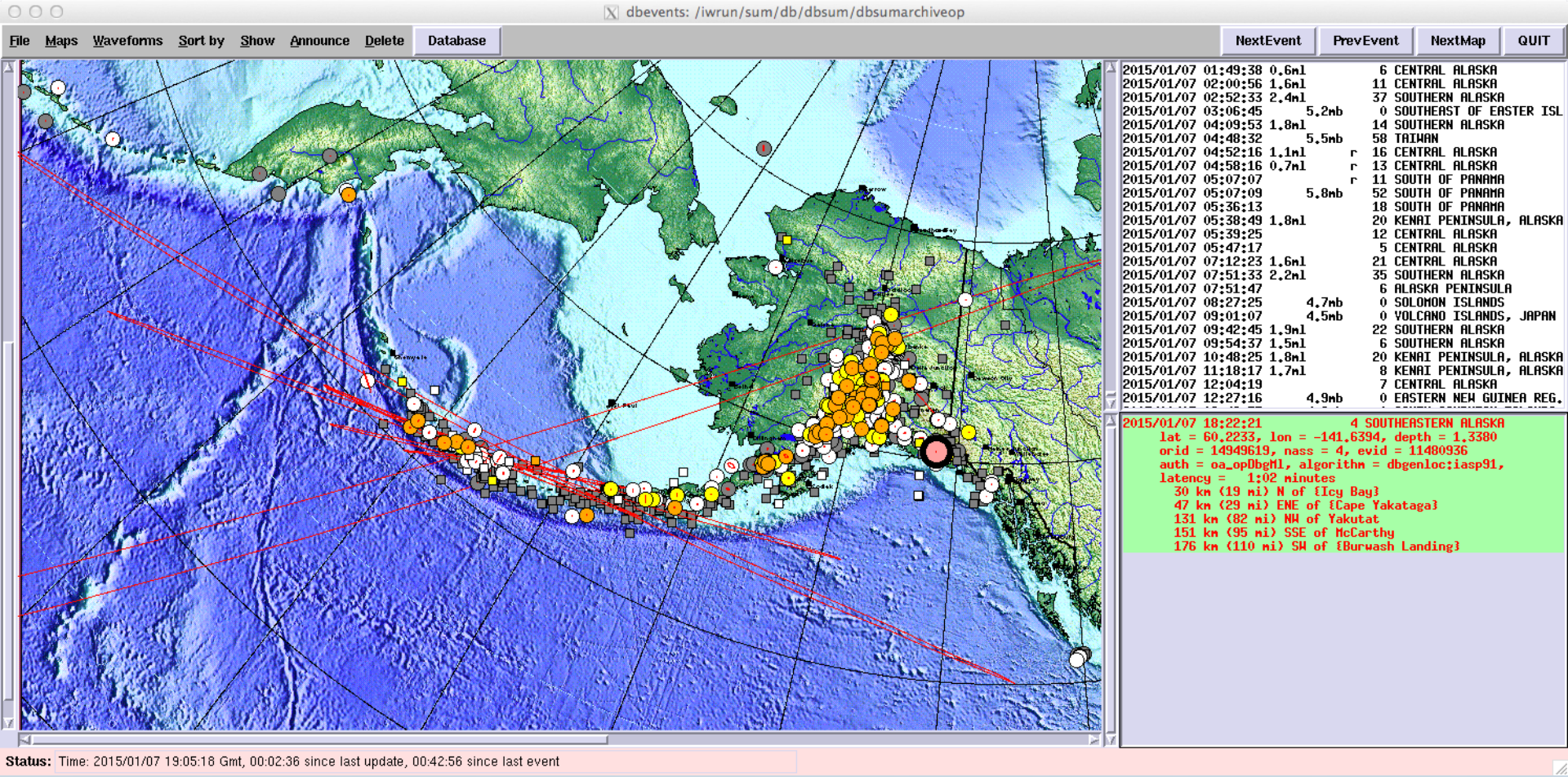


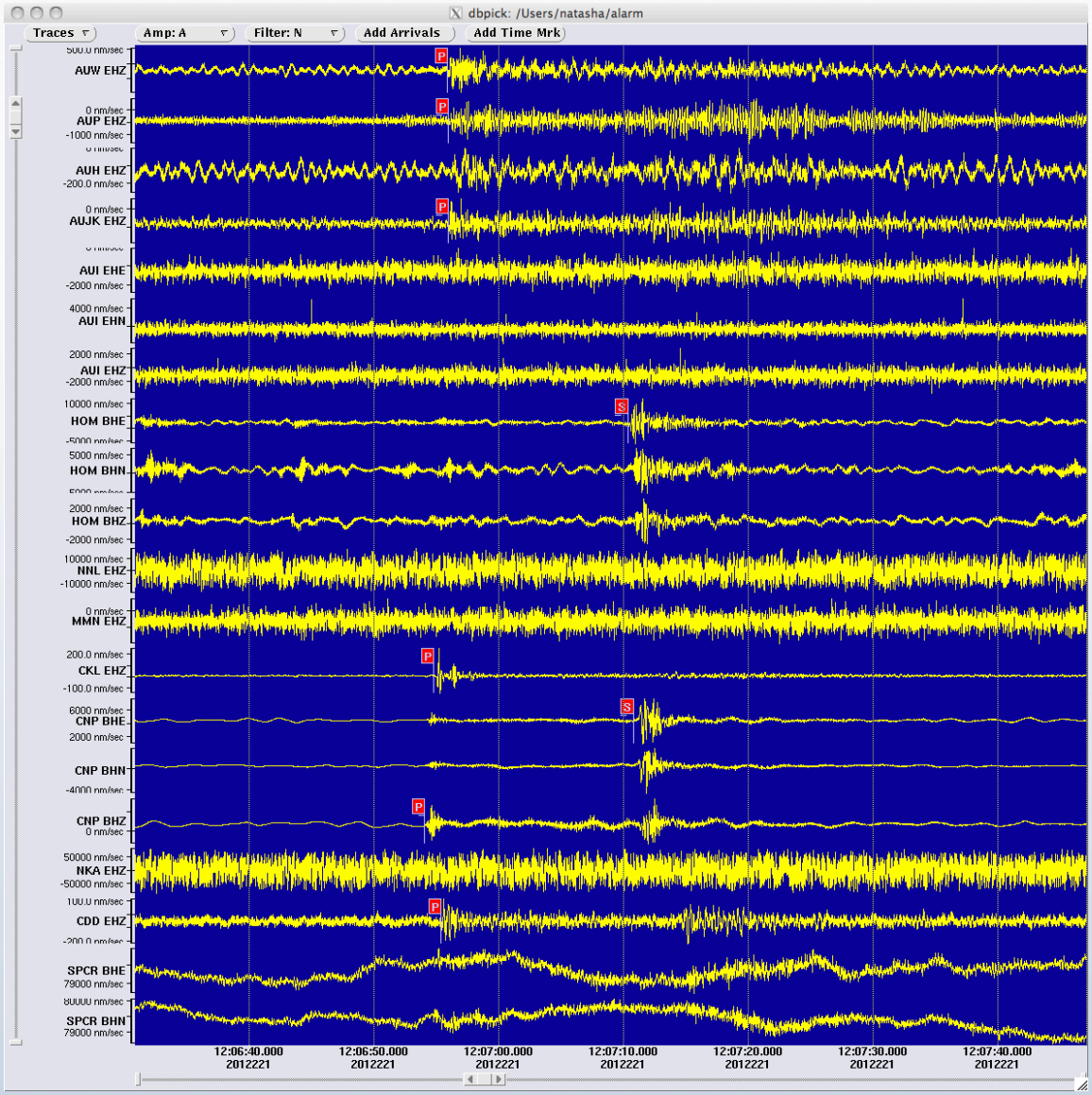
```
#           Following are required and are used as overall defaultsug

ave_type    rms         # Method for averaging (rms or filter)
sta_twin    1.0         # short term average time window
sta_tmin    1.0         # short term average minimum time for average
sta_maxtgap 0.5         # short term average maximum time gap
lta_twin    10.0        # long term average time window
lta_tmin    5.0         # long term average minimum time for average
lta_maxtgap 4.0         # long term average maximum time gap
nodet_twin              5.0         # no detection if on time is less than this
pamp        500.0       # plot amplitude
thresh                  4.0         # detection SNR threshold
threshoff   2.0         # detection-off SNR threshold
det_tmin    10.0        # detection minimum on time
det_tmax    500.0       # detection maximum on time
latency                 3           # input packet pipe latency (per channel) in packets
h                       0           # plot channel height in pixels
filter                  none        # default filter
iphase                  D           # default iphase for detections
maxfuturetime           600.0       # Maximum number of seconds after system wall clock time
goodvalue_min           0.0         # Minimum "good" data value
goodvalue_max           0.0         # Maximum "good" data value


#           At least one default band must be set set up in the bands table
#           parameter values override default values above for each band

bands       &Tbl{
            &Arr{
                        sta_twin    1.0
                        sta_tmin    1.0
                        sta_maxtgap 0.5
                        lta_twin    10.0
                        lta_tmin    5.0
                        lta_maxtgap 4.0
                        pamp                500.0
                        filter              BW 1.0 4 0 0
                        iphase              r
            }
}
```

```
netstachanlocs              &Tbl{
# Akutan
#               AV_AHB_EHZ out
                AV_AKBB_BH[NEZ]
                AV_AKGG_BH[NEZ]
                AV_AKLV_BH[NEZ]
                AV_AKMO_BH[NEZ]
                AV_AKRB_BH[NEZ]
#               AV_AKS_EH[NEZ]
                AV_AKSA_BH[NEZ]
#               AV_AKT_BH[NEZ]
#               AV_AKV_EHZ out
                AT_AKUT_BH[NEZ]
#               AV_HSB_EHZ out
#               AV_LVA_EHZ
#               AV_ZRO_EHZ out
# Augustine
                AV_AU22_BH[ENZ]
                AV_AUCH_BH[ENZ]
#               AV_AUE_EHZ
#               AV_AUH_EHZ
#               AV_AUI_EH[NEZ]
#               AV_AUJA_BH[ENZ]
#               AV_AUJK_EHZ
                AV_AUL_BH[ENZ]
#               AV_AUL_EHZ noisy
#               AV_AUNW_EHZ
#               AV_AUP_EHZ
                AV_AUQ_BH[ENZ]
#               AV_AUW_EHZ
# Cleveland
                AV_CLCO_BH[ENZ]
#               AV_CLEO_BH[ENZ]
                AV_CLES_BH[ENZ]
# Dutton
#               AV_BLDY_EHZ
#               AV_DRR3_EHZ
                AV_DT1_EHZ
#               AV_DTN_EHZ off 12/9/2011 noisy
.........
# Regional
                AV_ADAG_EHZ
                IU_ADK_BH[NEZ]
                IU_ADK_BH[12Z]_00
#               IU_ADK_BH[12Z]_10
                AV_AMKA_BH[ENZ]
                AK_ANM_BH[NEZ]
                AK_ATKA_BH[NEZ]
.........
# Teleseismic
                II_.*_(BHZ|BHZ_00)
                IU_.*_(BHZ|BHZ_00)
                CI_.*_(BHZ|BHZ_00)
                CU_.*_(BHZ|BHZ_00)
.........
# TA Alaska and Canada
                TA_A21K_BH[ENZ]
                TA_EPYK_BH[ENZ]
                TA_I23K_BH[ENZ]
                TA_K27K_BH[ENZ]
.........
}
```

```
#   Parameter file for orbgrassoc
process_time_window     600.0       # Main detection processing time window
process_ncycle          30          # how often to do detection processing, in detections
process_tcycle          0.0         # how often to do detection processing, in time
process_timeout         300         # timeout for processing detections

grid_params &Arr{
        scak_shal &Arr{
        nsta_thresh &Tbl{   # Minimum allowable number of stations
                                    # expressed as a function of maximum
                                    # source-receiver distance
                2.0   4
                4.0   6
                6.0   8
                10.0  10
                180.0 20
        }
#       nsta_thresh    6            # Minimum allowable number of stations
#       changed on 20110311 by Mitch
#       number_threads 16   # Number of simultaneous threads to use for this grid
        number_threads 10   # Number of simultaneous threads to use for this grid
        nxd                 11          # Number of east-west grid nodes for depth scans
        nyd                 11          # Number of north-south grid nodes for depth scans
        cluster_twin   3.0          # Clustering time window
        try_S                       no          # yes = Try observations as both P and S
                                    # no  = Observations are P only
        drop_if_on_edge             yes         # Drop if solution is on the edge of the grid
        associate_S    yes          # yes = Try to associate observations as both P and S
        reprocess_S    yes          # yes = Reprocess when new S-associations found
        phase_sifter   r
        algorithm      scak_shal
        P_deltim       0.1  # Default deltim value for arrival table rows for P arrivals
        S_deltim       0.2  # Default deltim value for arrival table rows for S arrivals
        P_channel_sifter ..Z|..Z_00 # Only do P associations with channels that match this expression
        S_channel_sifter ..[NE12]|..[NE12]_00 # Only do S associations with channels that match this expression
        P_det_tmin     10           # This is a time window in seconds for culling closely
         # spaced detections before initial P association processing
#       priority       2
#       sta_weight_radius           1.0
        use_dwt        yes
#    dwt_dist_near  2.0
#    dwt_wt_near    1.0
#    dwt_dist_far   6.0
#    dwt_wt_far     0.1
    dwt_tbl &Tbl{       # distance weights can be input using a table or with
        0.0   2.0   # the dwt_dist_near, ... parameters
                4.0   1.0
                10.0  0.0
    }
        use_dwts       yes   # yes = Use source receiver distance weighting factor (or no)
#                             # this one is for S associations
    dwts_dist_near  2.0
    dwts_wt_near    1.0
    dwts_dist_far   4.0
    dwts_wt_far     0.0
        closest_stations   40  # Use only the 20 closest stations to a particular source
#       sta_defining_pxmin 0.0  # Use only stations that are to the east of the
                                    # west edge of the search grid for defining phases
#       sta_defining_pxmax 100.0# Use only stations that are to the west of the
                                    # east edge of the search grid for defining phases
#       sta_defining_pymin 0.0  # Use only stations that are to the north of the
                                    # south edge of the search grid for defining phases
#       sta_defining_pymax 100.0# Use only stations that are to the south of the
                                    #                 north edge of the search grid for defining phases
        nondefining_association_P_maxresid 5.0 # maximum residual for non-defining P arrival associations
        nondefining_association_S_maxresid 5.0 # maximum residual for non-defining S arrival associations
        relocate           rundbgenloc # Run this relocation script to refine final solution
        use_only_relocation yes # If relocation converges, just output the relocation
        }
        tele_uni &Arr{
#       nsta_thresh &Tbl{   # Minimum allowable number of stations
#                                   #   expressed as a function of maximum
#                                   #   source-receiver distance
#               4.0   6
#               6.0   8
#               180.0 10
#       }
        nsta_thresh    12           # Minimum allowable number of stations
#       changed on 20110311 by Mitch
#       number_threads 16   # Number of simultaneous threads to use for this grid
        number_threads 8    # Number of simultaneous threads to use for this grid
        cluster_twin   4.0          # Clustering time window
        try_S                       no          # yes = Try observations as both P and S
                                    # no  = Observations are P only
        drop_if_on_edge             no          # Drop if solution is on the edge of the grid
        associate_S    yes  # yes = Try to associate observations as both P and S
        reprocess_S    yes  # yes = Reprocess when new S-associations found
        phase_sifter   r
        algorithm      teleseismic
#       priority       1
        P_deltim       0.1  # Default deltim value for arrival table rows for P arrivals
        S_deltim       0.2  # Default deltim value for arrival table rows for S arrivals
        P_channel_sifter ..Z|..Z_00 # Only do P associations with channels that match this expression
        S_channel_sifter ..[NE12]|..[NE12]_00 # Only do S associations with channels that match this
expression
        P_det_tmin     10           # This is a time window in seconds for culling closely
         # spaced detections before initial P association processing
#       sta_weight_radius           5.0
        use_dwt        no
    dwt_tbl &Tbl{
       0.0   2.0
       2.0   1.0
      10.0   0.5
      90.0   0.1
    }
        use_dwts       no
    dwts_dist_near  2.0
    dwts_wt_near    1.0
    dwts_dist_far   4.0
    dwts_wt_far     0.0
#       closest_stations   40  # Use only the 20 closest stations to a particular source
#       sta_defining_pxmin 0.0  # Use only stations that are to the east of the
                                    # west edge of the search grid for defining phases
#       sta_defining_pxmax 100.0# Use only stations that are to the west of the
                                    # east edge of the search grid for defining phases
#       sta_defining_pymin 0.0  # Use only stations that are to the north of the
                                    # south edge of the search grid for defining phases
#       sta_defining_pymax 100.0# Use only stations that are to the south of the
                                    # north edge of the search grid for defining phases
        nondefining_association_P_maxresid 3.0 # maximum residual for non-defining P arrival associations
        nondefining_association_S_maxresid 5.0 # maximum residual for non-defining S arrival associations
        relocate           rundbgenloc # Run this relocation script to refine final solution
        use_only_relocation yes # If relocation converges, just output the relocation
        }
```

Real-time earthquake map





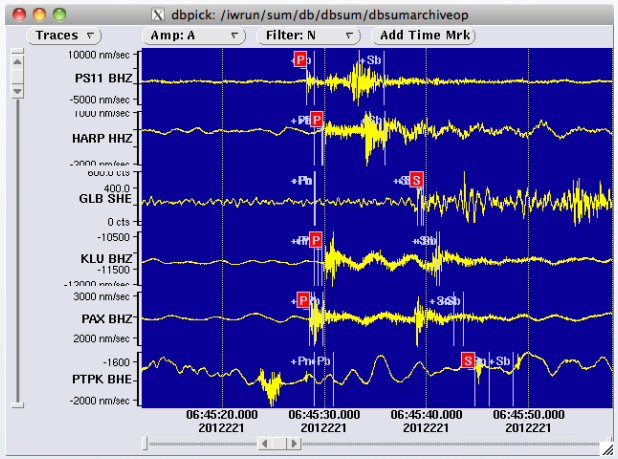
Problem: Data quality

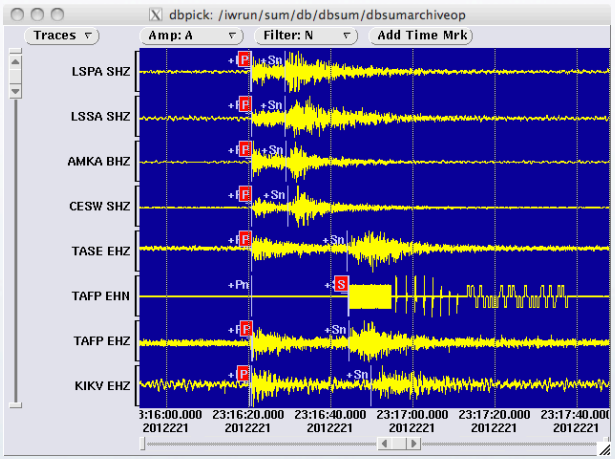
Ex.: ~M2 earthquake in southern Alaska, intermediate depth.

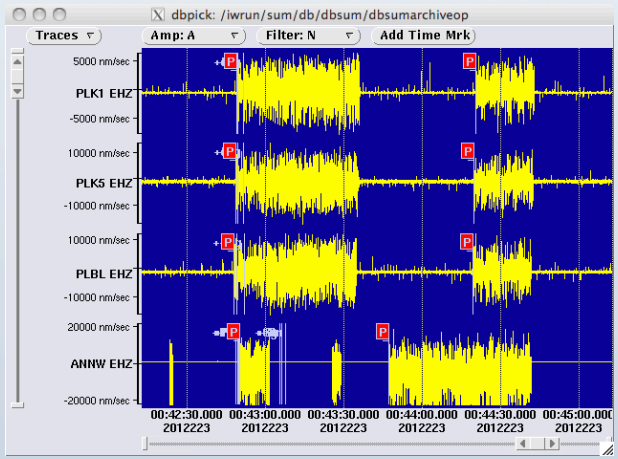
Multiple stations are out. Problem with analog telemetry: even when sensor is not working, the data is still being transmitted.

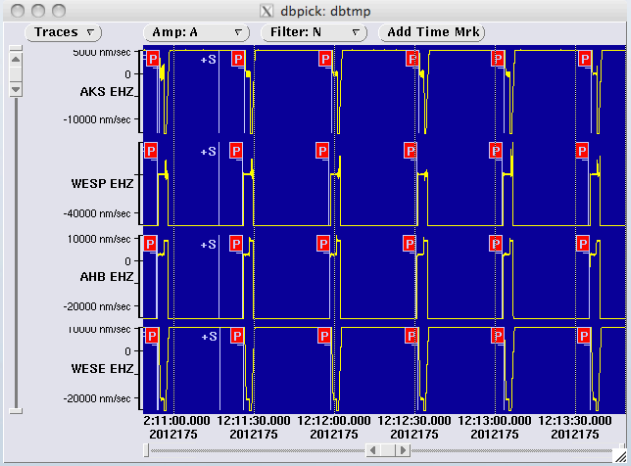
We carefully monitor state of health of our stations and exclude bad stations from auto-detector list.

Problem: Data quality





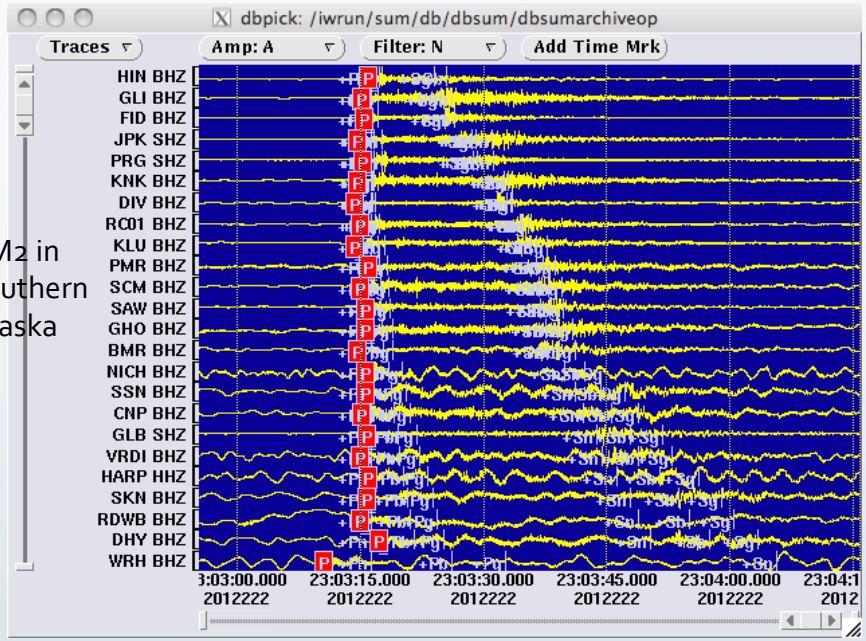


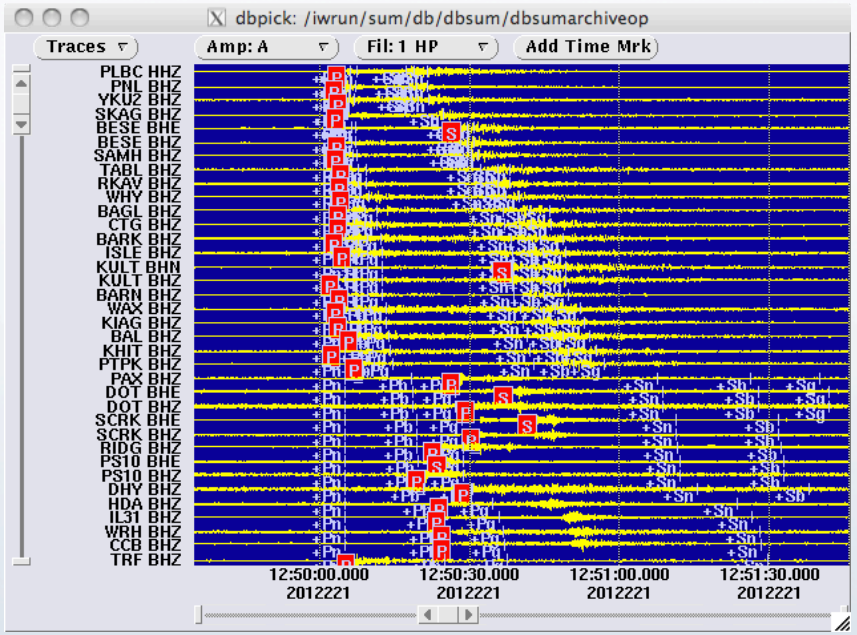


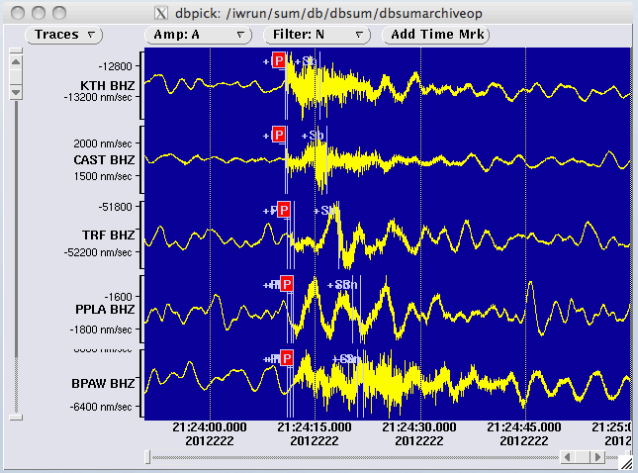
- Despite our best efforts to monitor data quality, bad picks still make it into earthquake associations.
- We can correct these events through analyst reviews and event deletes.
- Or we can be proactive and tune our associator so that it produces minimal amount of mis-locations.

Automatic detection examples

~M2 in southern Alaska

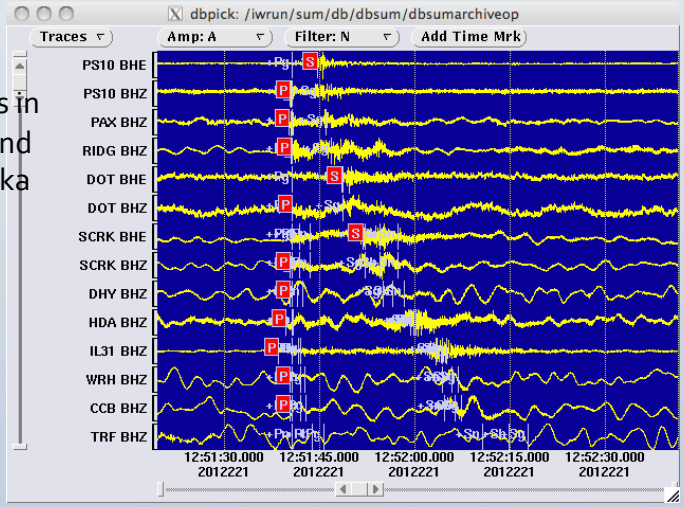






~M1 in central Alaska

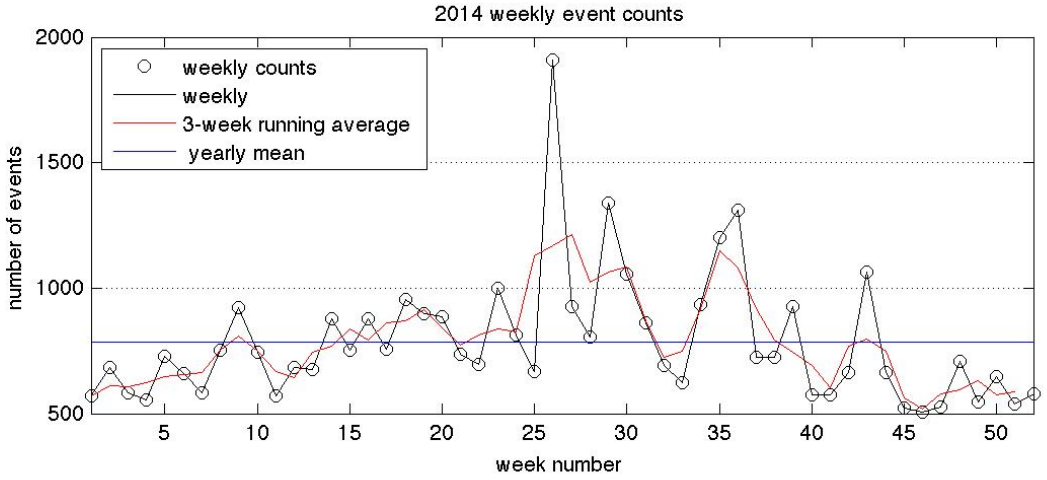
Two concurring earthquakes in southeast and central Alaska

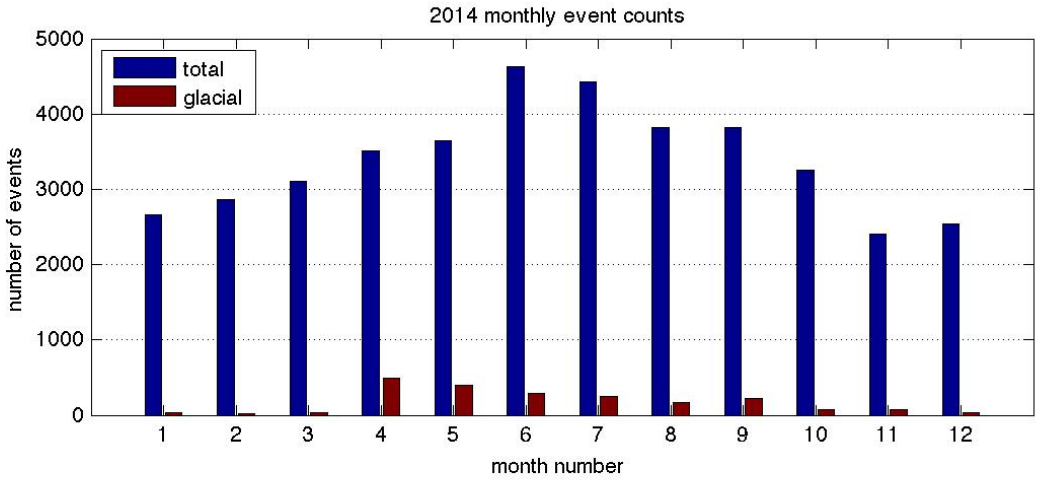


Performance Area	Metric (explanations below)	Units	Performance Standard: Hi-Risk Urban Areas	Mod-High Hazard Areas	National	Global
Seismic Monitoring/Strong Earthquake Shaking						
1.1	Magnitude Completeness Level	M	2.0	2.5	3.0	4.5
1.2	Epicenter Uncertainty	km	2	5	10	20
1.3	Depth Uncertainty	km	4	10	10	20
1.4	Magnitude Uncertainty for M≥ 4.5	M	±0.2			
1.5	Magnitude Estimation Accuracy (Md, Ml, Mo, Mb) for M<4.5	M	to be determined			NA
1.6	Network average station uptime	%	90			
1.7	Waveform Data Return Rate for Triggered data	%	95			NA
Real-Time/Automated Product Generation						
2.1	Hypocenter Post Time	min.	2	4	6	15
2.2	Magnitude Post Time	min.	3	4	6	15
2.3	Moment Tensor Post Time M≥4.5 (M≥5.5 non-US)	min.	15			30
2.4	Initial *Internet Quick Report* Post Time M≥3.5	min.	15	15	30	NA
2.5	*ShakeMap* Post Time	min.	5	10	15	20
Preparation of Seismologist-Reviewed Products for Significant Earthquakes						
3.1	Reviewed Hypocenter Post Time	min.	10			20
3.2	Reviewed Magnitude Post Time	min.	10			20
3.3	Reviewed Moment Tensor Post Time M≥4.5 (M≥5.5 non-US)	min.	30			
3.4	Reviewed *Internet Quick Report* Post Time	min.	30	45	60	NA
3.5	Reviewed *ShakeMap* Post Time	min.	15	30	30	60
Data Exchange Between ANSS Networks						
4.1	Waveform Availability Timeliness	sec.	30		60	
4.2	Amplitude Availability Timeliness	sec.	30		60	
4.3	Phase Picks Availability Timeliness	sec.	30		60	
Data Archiving and Public Distribution						
5.1	Availability of Waveforms to External Users	min.	60			
5.2	Availability of Event Bulletin (parametric data)	min.	60			120
5.3	Metadata availability (current)	%	99			
5.4	Data import into archive	%/t	to be determined			

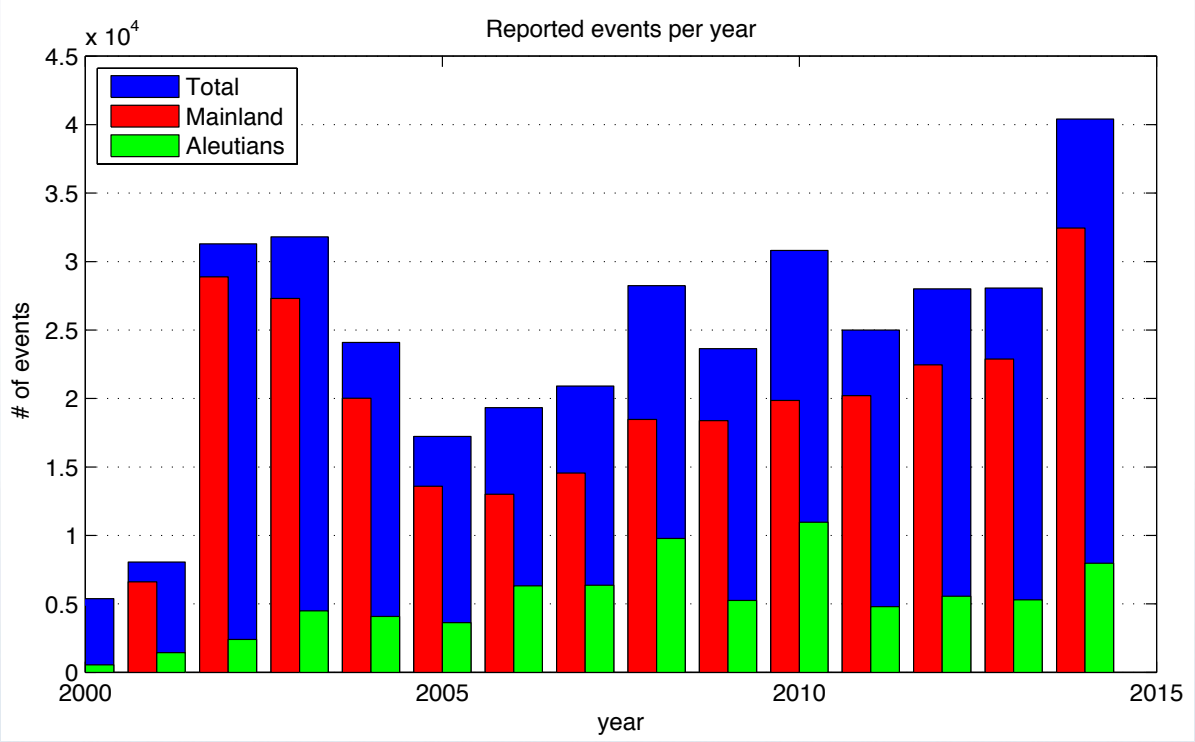
- AEIC is participating member of the ANSS (Advanced National Seismic Network)
- We report on network's performance yearly, in accordance with our funding requirements.
- We meet or exceed most of the requirements, especially for reporting latency and earthquake location errors.

2014 earthquake counts





- A total of 40,686 events reported in 2014
- Previous record was ~33K events in 2003, following the M7.9 Denali fault earthquake
- ~7K are various aftershocks
- ~2K are glacial events



- We reported over 40,000 seismic events in 2014, which is about 40% increase relative to 2012 and 2013
- Nearly 7,000 of the reported events are various aftershocks
- About 2,000 are glacial events

Seismic station CRQ in St.Elias Mnts, southern Alaska.
Photo by Dara Merz, Alaska Earthquake Center