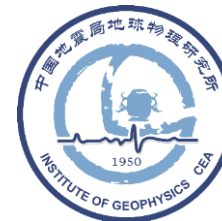


# Two Complete Architectures for Automatic Earthquake Detection and Location: *Part 2. Running PAL & MESS*

*speaker:* Yijian ZHOU<sup>1</sup>

Abhijit GHOSH<sup>1</sup>, Lihua FANG<sup>2</sup>, Han YUE<sup>3</sup>, Shiyong ZHOU<sup>3</sup>

*contact info:* [yijian.zhou@email.ucr.edu](mailto:yijian.zhou@email.ucr.edu)



# Outline

- Hardware & software
- Running PAL
- Running MESS

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- **Hardware & software**
- Running PAL
- Running MESS

# Hardware Requirements

- CPU
  - number of CPU threads > number of processes allocated
  - e.g. 4C8T CPU can allocate up to 8 parallel PAL processes
- GPU
  - Nvidia RTX series, suggest >4G GPU memory
  - e.g. RTX 3060 12G
- Memory & Hard drive
  - baseline >8G, suggest >16G memory
  - SSD is great, HDD also works



Hard Drive	
1~10 Tb	SATA



100M/s 

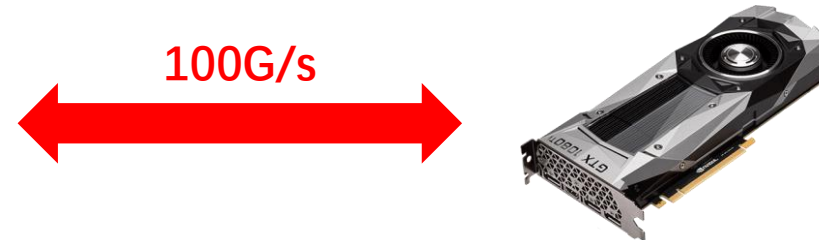
Memory	
100 Gb	PCIe



  
15G/s

15G/s 

Graphics Memory	
10 Gb	GDDR



  
100G/s

# Software Requirements

- Anaconda
  - <https://www.anaconda.com/products/individual>
  - Numpy, Scipy etc. are included
- Obspy
  - <https://github.com/obspy/obspy/wiki/Installation-via-Anaconda>
  - processing seismic data
- Pytorch
  - <https://pytorch.org/>
  - deep learning architecture, GPU computation

# “Install” PALM

- Setup software environment
  - suggest installing Anaconda & Obspy & Pytorch sequentially
- Download code from Github (latest release v2.3)
  - suggest saving at /home/user/software
- Install HypoInverse & HypoDD
  - suggest saving the binary file at /home/user/bin
- *Go through the example dataset*

# Download Example Data

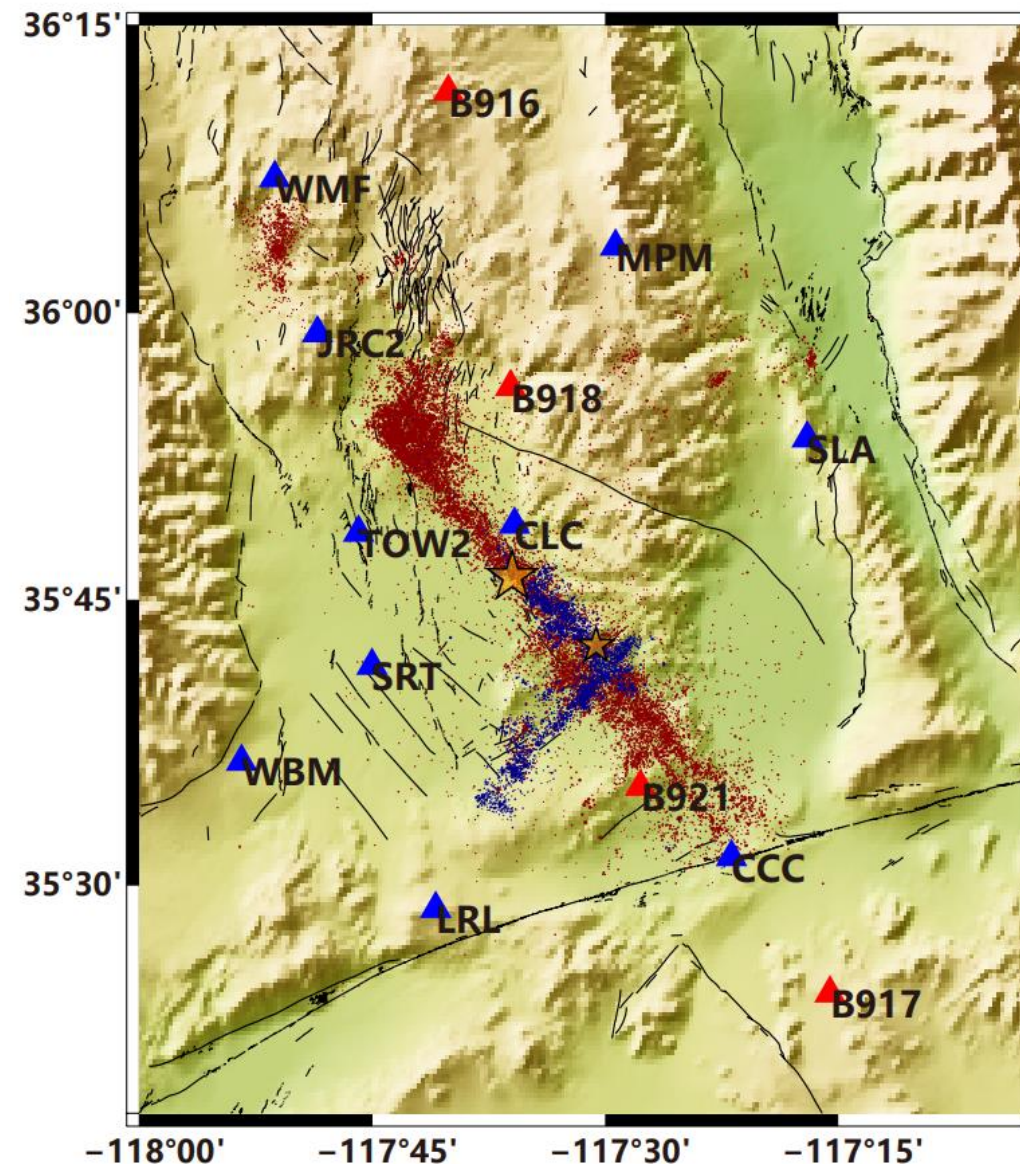
master ▾ PAL / example\_pal\_workdir / down\_stp\_data\_eg.py / <> Jump to ▾

 YijianZhou update example

1 contributor

52 lines (49 sloc) | 1.74 KB

```
1  """ Download Example SCSN data by STP
2  STP can be downloaded from https://scedc.caltech.edu/data/stp/index.html
3  """
4  import os, shutil, glob
5  from obspy import UTCDateTime
6  import subprocess
7  import multiprocessing as mp
8
9  # i/o files
10 num_workers = 10
11 fsta = 'input/example_pal.sta'
12 time_range = '20190704-20190707'
13 out_root = '/data/Example_data'
14 if not os.path.exists(out_root): os.makedirs(out_root)
15 start_time, end_time = [UTCDateTime(date) for date in time_range.split('-')]
16 num_days = (end_time.date - start_time.date).days
```



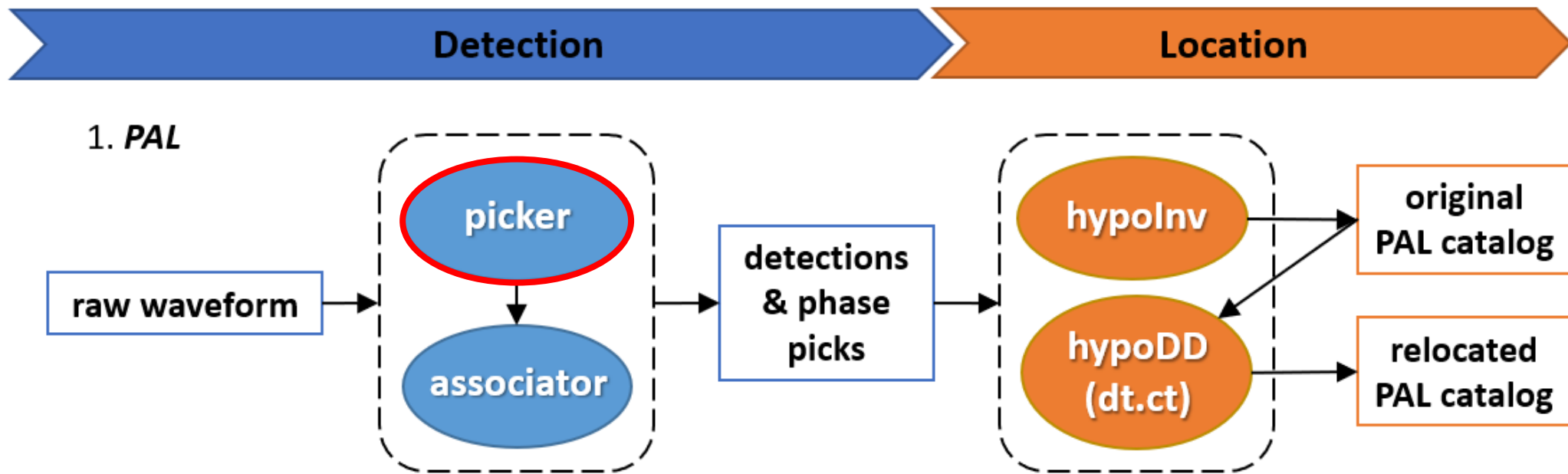


# Outline

- Hardware & software
- **Running PAL**
- Running MESS

<https://github.com/YijianZhou/PAL/releases/tag/v2.3>

YijianZhou Update README.md		ba95297 37 seconds ago	🕒 268 commits
env	Update pal.yml	3 months ago	
example_pal_workdir	provide example data	4 months ago	
hypodd	specific hypo_root	4 months ago	
hypoinverse	Update mk_pha.py	4 months ago	
README.md	Update README.md	37 seconds ago	
associator_pal.py	Update associator_pal.py	4 months ago	
config.py	Update config.py	6 months ago	
data_pipeline.py	provide example data	4 months ago	
picker_pal.py	Update picker_pal.py	3 months ago	
run_assoc.py	3D assoc	6 months ago	
run_pick_assoc.py	3D assoc	6 months ago	



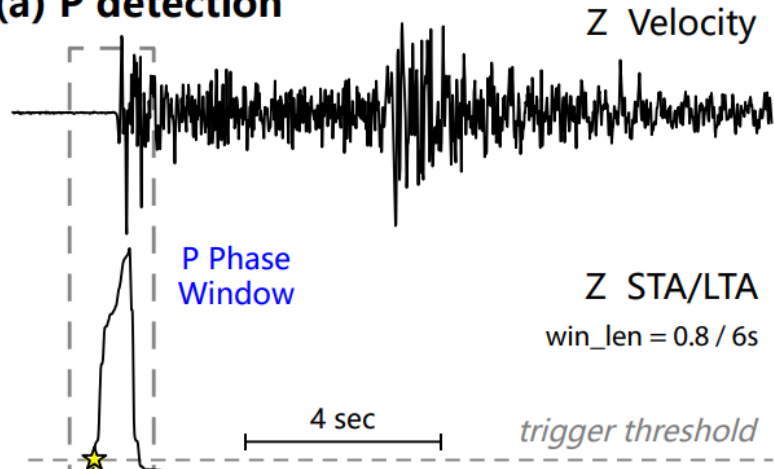
<https://github.com/YijianZhou/PAL>

Zhou et al., SRL 2021

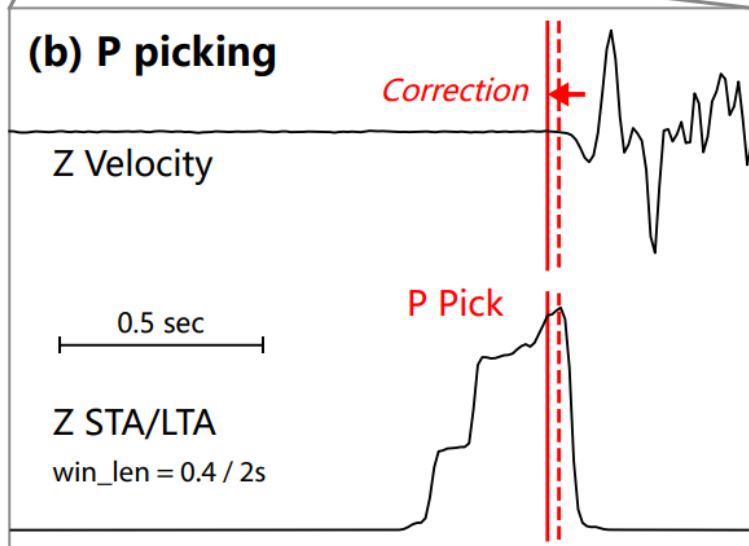
# PAL Config 1: Picking

```
# 1. picker params
self.win_sta      = [0.8, 0.4, 1.] # win for STA: det, p, s
self.win_lta      = [6., 2., 2.]  # win for LTA: det, p, s
self.win_kurt      = [5., 1.]      # win for kurtosis: long & short
self.trig_thres    = 12.           # threshold to trig picker (by energy)
self.p_win         = [.5, 1.]      # search win for P
self.s_win         = 10.           # search win for S
self.pca_win       = 1.            # win_len for PCA filter
self.pca_range     = [0., 2.]      # time range to apply PCA filter
self.fd_thres      = 2.5           # min value of dominant frequency
self.amp_win       = [1., 4.]      # time win to get S amplitude
self.det_gap       = 5.            # time gap between detections
self.to_prep       = True          # whether to preprocess the raw data
self.freq_band     = [2, 40]       # frequency band
```

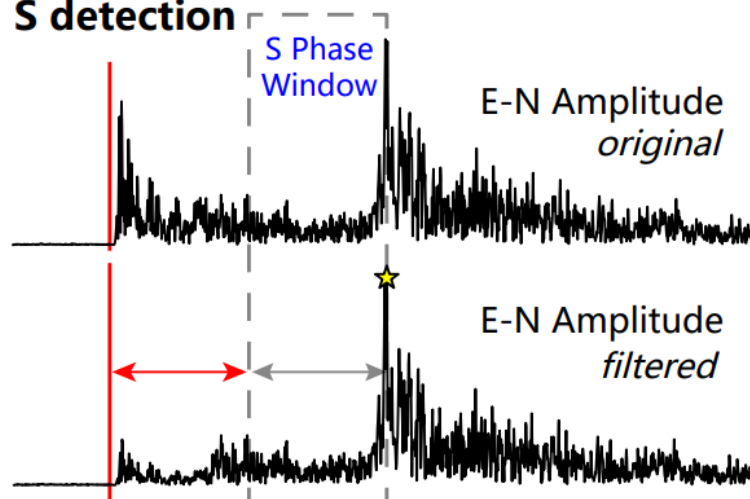
### (a) P detection



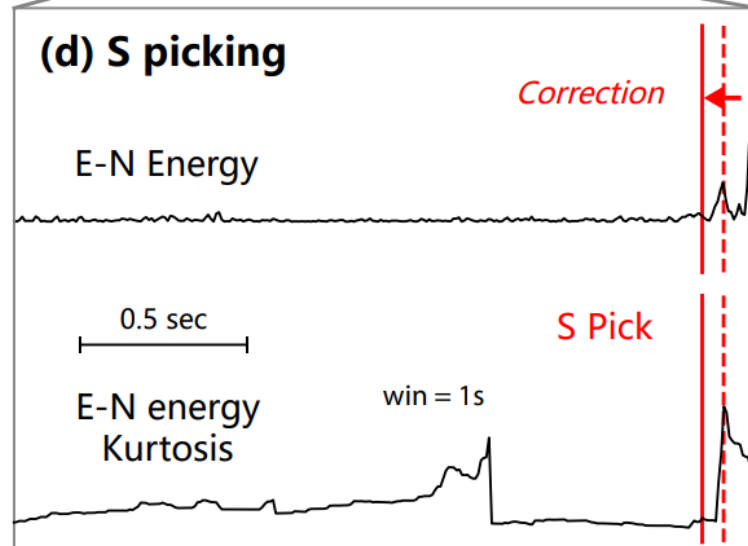
### (b) P picking



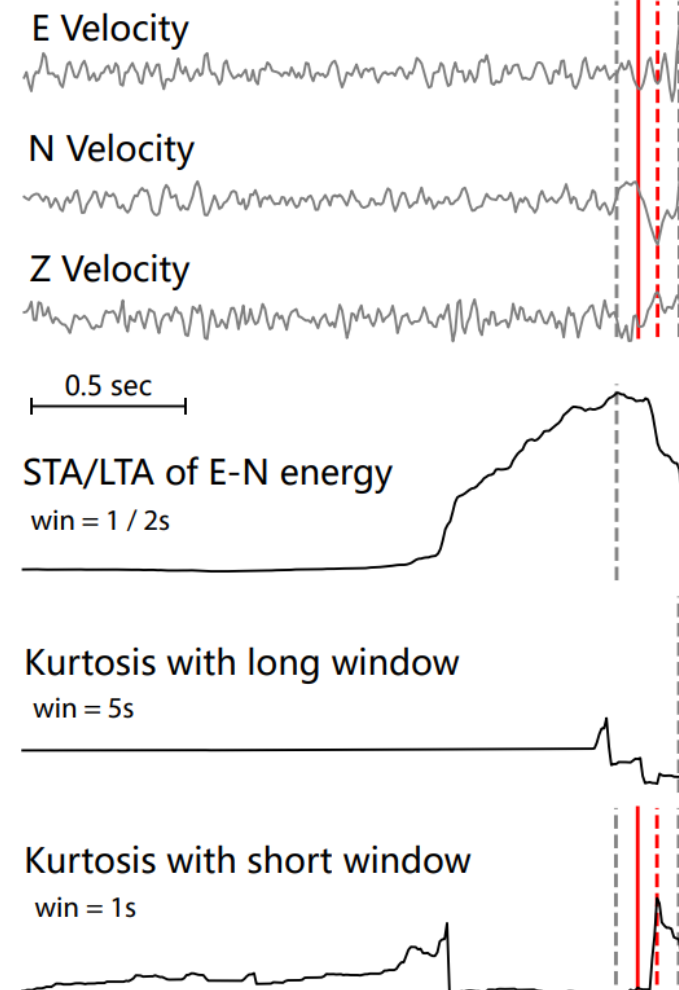
### (c) S detection



### (d) S picking



### (e) S picking (in detail)



# PAL Config 1: Picking

```
# 1. picker params
```

```
self.win_sta = [0.8, 0.4, 1.]
```

```
self.win_lta = [6.0, 2.0, 2.]
```

```
self.win_kurt = [5., 1.]
```

```
self.trig_thres = 12.
```

```
self.p_win = [.5, 1.]
```

```
self.s_win = 10.
```

```
self.pca_win = 1.
```

```
self.pca_range = [0., 2.]
```

```
self.fd_thres = 2.5
```

```
self.amp_win = [1., 4.]
```

```
self.det_gap = 5.
```

```
self.to_prep = True
```

```
self.freq_band = [2, 40]
```

*suitable for most cases*

```
# win for STA: det, p, s
```

```
# win for LTA: det, p, s
```

```
# win for kurtosis: long & short
```

```
# threshold to trig picker (by energy)
```

```
# search win for P
```

```
# search win for S
```

```
# win_len for PCA filter
```

```
# time range to apply PCA filter
```

```
# min value of dominant frequency
```

```
# time win to get S amplitude
```

```
# time gap between detections
```

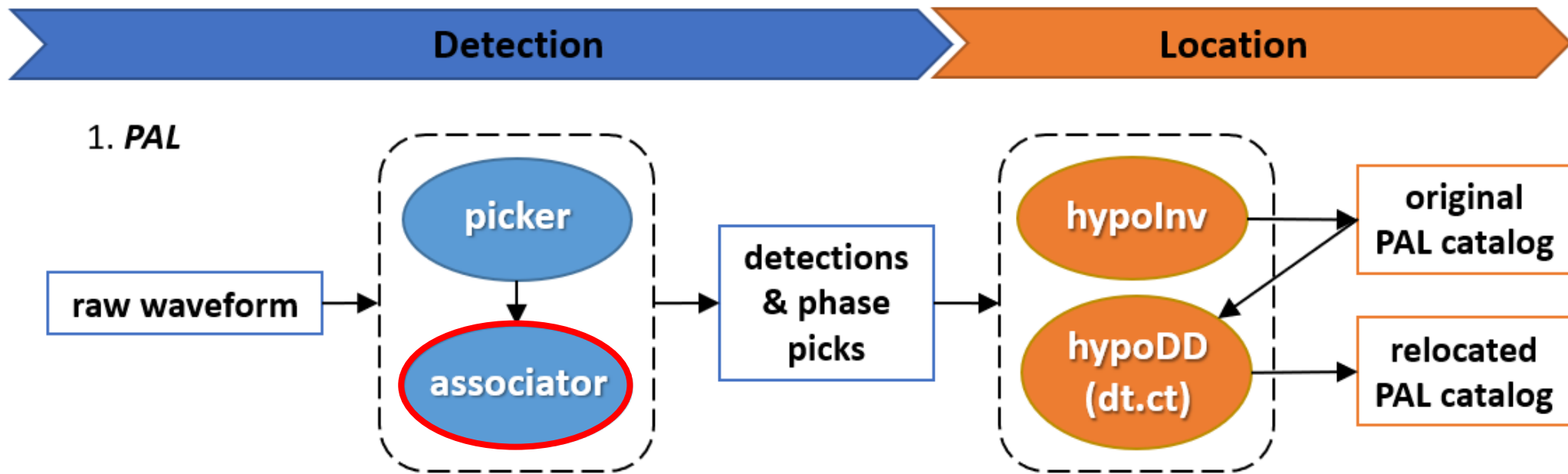
```
# whether to preprocess the raw data
```

```
# frequency band
```

# PAL Config 1: Picking

```
# 1. picker params
self.win_sta      = [0.8, 0.4, 1.] # win for STA: det, p, s
self.win_lta      = [6., 2., 2.]  # win for LTA: det, p, s
self.win_kurt      = [5., 1.]      # win for kurtosis: long & short
self.trig_thres   = 12.            # threshold to trig picker (by energy)
self.p_win        = [.5, 1.]       # search win for P
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self.fd_thres      = 2.5           # min value of dominant frequency
self.amp_win     = [1., 4.]       # time win to get S amplitude
self.det_gap       = 5.            # time gap between detections
self.to_prep       = True          # whether to preprocess the raw data
self.freq_band  = [2, 40]        # frequency band
```

Set picking params according to the *station distribution*  
(average inter-distance etc.) & noise level



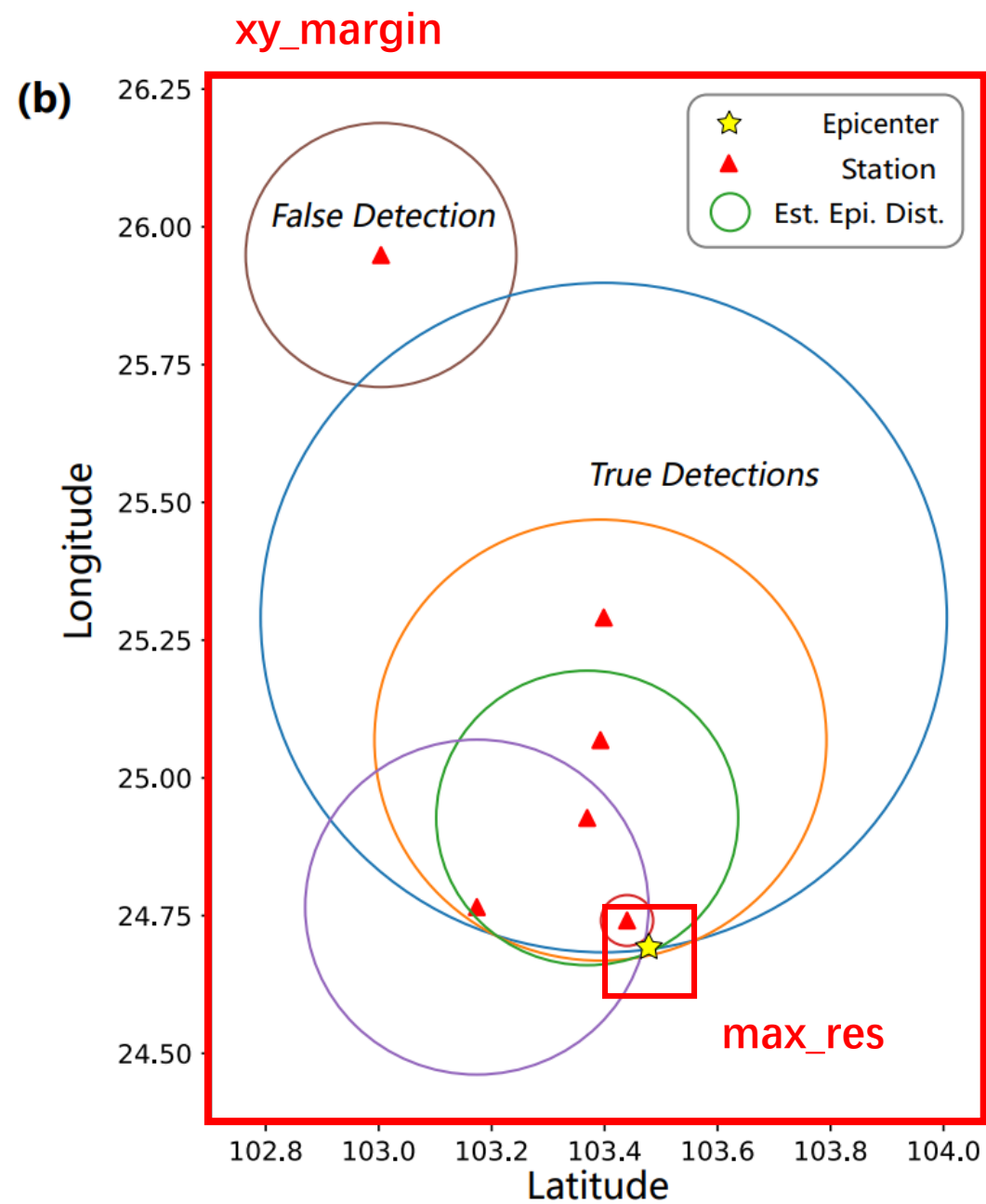
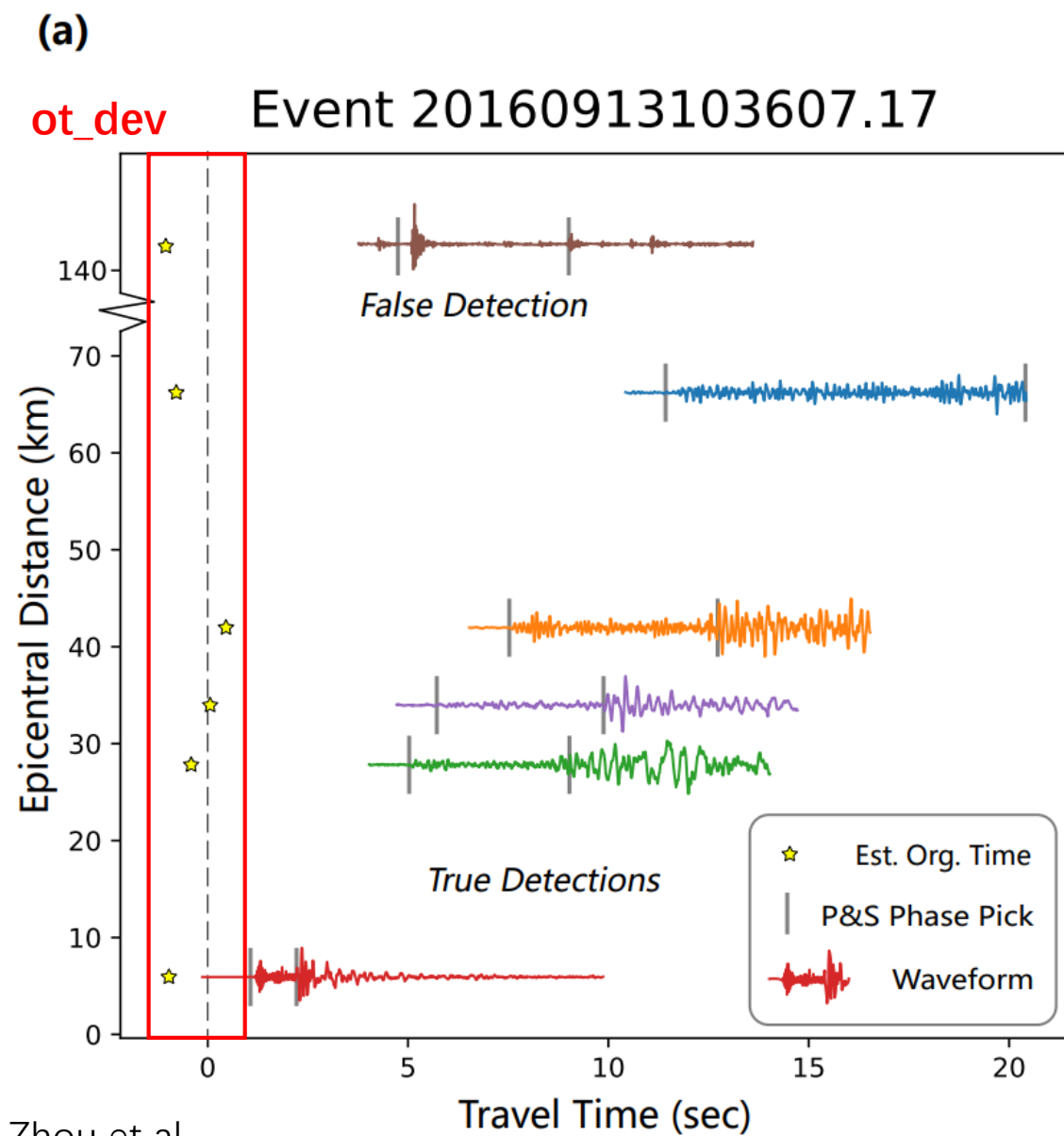
<https://github.com/YijianZhou/PAL>

Zhou et al., SRL 2021

# PAL Config 2: Association

```
# 2. assoc params
self.min_sta      = 4           # min num of sta to assoc
self.ot_dev       = 2.         # max time deviation for ot assoc
self.max_res      = 1.5       # max P res for loc assoc
self.xy_margin    = 0.1       # xy (lateral) range inferred from sta loc
self.xy_grid      = 0.02      # xy (lateral) grid size (in degree)
self.z_grids      = [5]       # z (dep) grids (in km)
self.vp           = 5.9       # averaged P velocity
```





# PAL Config 2: Association

```
# 2. assoc params
self.min_sta      = 4           # min num of sta to assoc
self.ot_dev       = 2.         # max time deviation for ot assoc
self.max_res      = 1.5        # max P res for loc assoc
self.xy_margin    = 0.1        # xy (lateral) range inferred from sta loc
self.xy_grid      = 0.02       # xy (lateral) grid size (in degree)
self.z_grids      = [5]        # z (dep) grids (in km)
self.vp           = 5.9        # averaged P velocity
```

**Set assoc params according to  
the station distribution  
(average inter-distance etc.)**

# PAL Data\_pipeline

1. Directory structure:  
data\_root/yyyymmdd/net.sta.date.chn.sac
2. Require 3-channel, naming as ENZ/123 etc.
3. Modify *get\_data\_dict* if necessary

```
# get data path dict
def get_data_dict(date, data_dir):
    # get data paths
    data_dict = {}
    date_code = '{:0>4}{:0>2}{:0>2}'.format(date.year, date.month, date.day)
    st_paths = sorted(glob.glob(os.path.join(data_dir, date_code, '*')))
    for st_path in st_paths:
        fname = os.path.basename(st_path)
        net_sta = '.'.join(fname.split('.')[0:2])
        if net_sta in data_dict: data_dict[net_sta].append(st_path)
        else: data_dict[net_sta] = [st_path]
    # drop bad sta
    todel = [net_sta for net_sta in data_dict if len(data_dict[net_sta])!=3]
    for net_sta in todel: data_dict.pop(net_sta)
    return data_dict
```

# PAL Data\_pipeline

Format of station file:

net.sta, sta\_lat, sta\_lon, sta\_ele, gain

```
# get station loc & gain dict
def get_sta_dict(sta_file):
    sta_dict = {}
    dtype = [('sta_lat', 'O'), ('sta_lon', 'O'), ('sta_ele', 'O'), ('gain', 'O')]
    f=open(sta_file); lines = f.readlines(); f.close()
    for line in lines:
        codes = line.split(',')
        net_sta = codes[0]
        lat, lon, ele, gain = [float(code) for code in codes[1:5]]
        sta_dict[net_sta] = np.array((lat,lon,ele,gain), dtype=dtype)
    return sta_dict
```

# Running PAL

- Pick + Assoc: *parallel\_pick\_assoc.py*
- Assoc only: *parallel\_assoc.py*

```
pal_dir = '/home/zhouyj/software/PAL'
shutil.copyfile('config_eg.py', os.path.join(pal_dir, 'config.py'))
data_dir = '/data/Example_data'
time_range = '20190704-20190707'
sta_file = 'input/example_pal.sta'
num_workers = 3
out_root = 'output/eg'
out_pick_dir = 'output/eg/picks'
```

1. Parallel by time, the minimum unit is 1 day
2. Set date for *time\_range*, but they are used as time (*end date + 1*)
3. Run *python parallel\_pick\_assoc.py*
4. In the output dir: *cat phase\_\* > pal.pha*

# PAL Output

- PAL output picks
  - fpath: out\_root/picks/yyyy-mm-dd.pick
  - format: net.sta, ot, tp, ts, s\_amp, p\_snr, freq\_dom
- PAL output phase file
  - fpath: out\_root/phase\_yyyymmdd-yyymmdd.dat
  - event line: ot, lat, lon, dep, mag
  - phase line: net.sta, tp, ts, s\_amp, p\_snr

# Pick-based Location

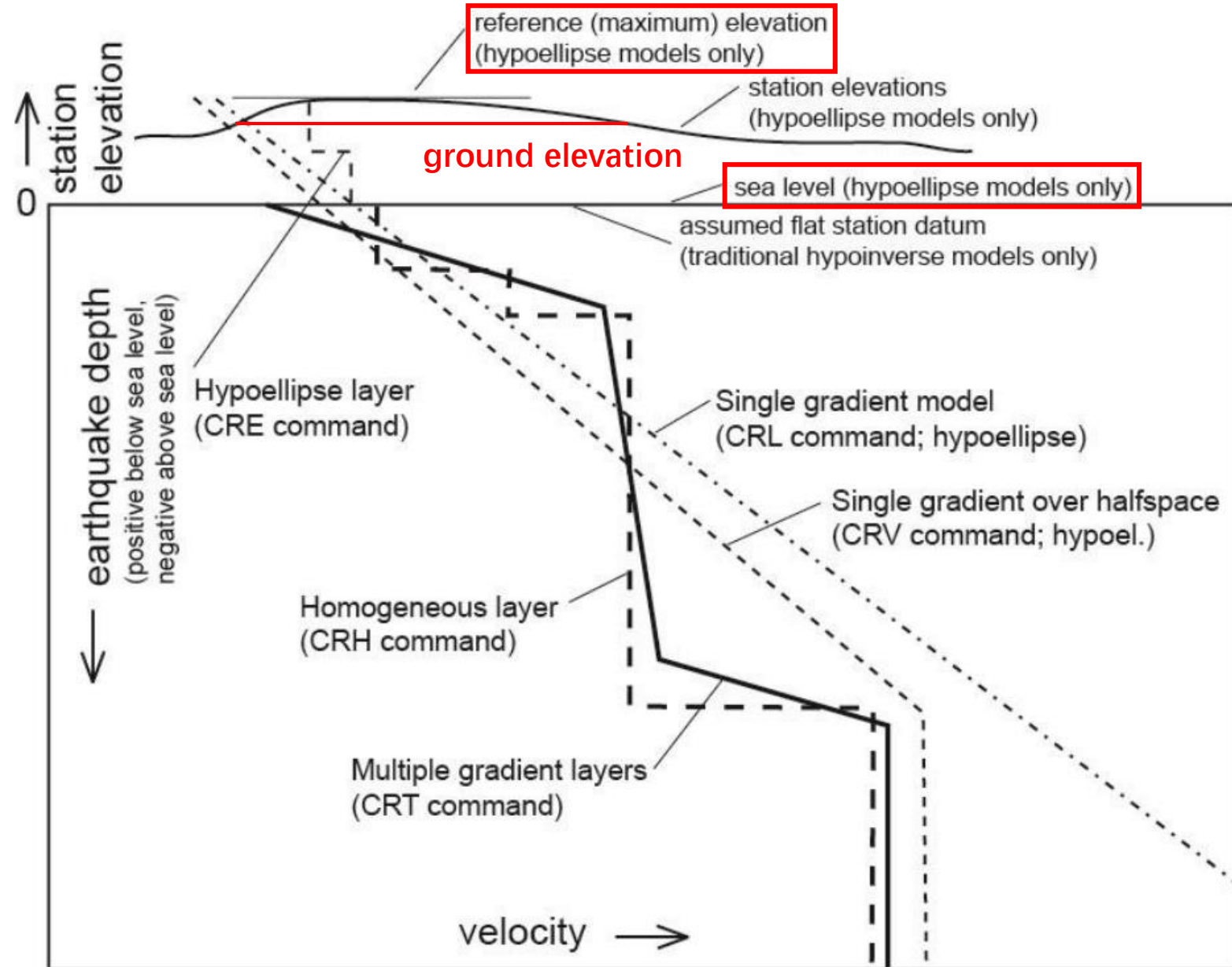
- HypoInverse
  - Software: <https://www.usgs.gov/software/hypoinverse-earthquake-location>
  - Document: <https://doi.org/10.3133/ofr02171>
- HypoDD (dt.ct)
  - Software: <https://www.ldeo.columbia.edu/~felixw/hypoDD.html>
  - Document: [https://www.ldeo.columbia.edu/~felixw/papers/Waldhauser\\_OFR2001.pdf](https://www.ldeo.columbia.edu/~felixw/papers/Waldhauser_OFR2001.pdf)

# Run HypoInverse

- Station file
  - same as PAL, just copy into input/
- Velocity model
  - in CRE format, which supports station elevation
  - set *ref\_ele* & *grd\_ele*, make necessary correction
- Location parameters
  - weighting by distance
  - weighting by residual



# Crustal model types



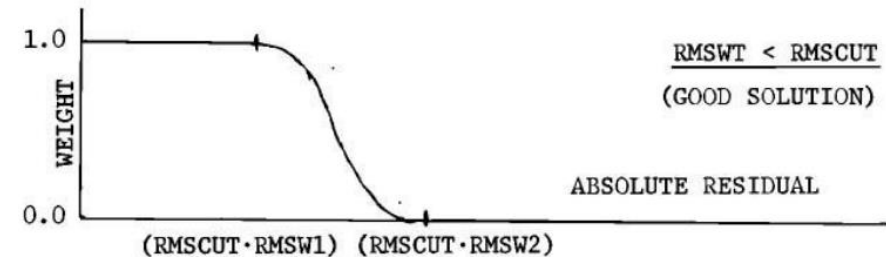
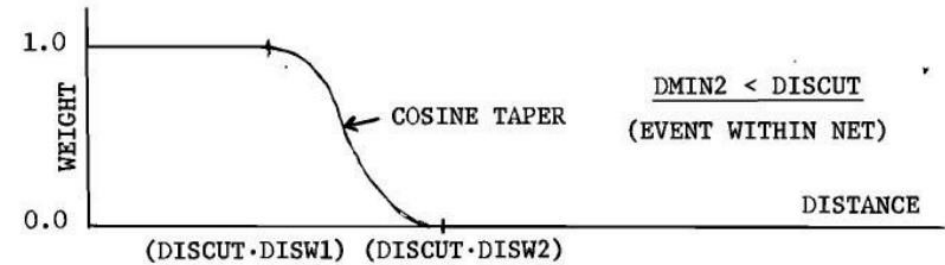
```
self.ctrlg_code = 'eg_pal_hyp'
# 1. mk_sta: format station file
self.fsta = 'input/example_pal.sta'
self.lat_code = 'N'
self.lon_code = 'W'
# 2. mk pha: format phase file
self.fpha = 'input/eg_pal.pha'
# 3. sum2csv: format output files
self.ref_ele = 2.5 # ref ele for CRE mod (max sta ele)
self.grd_ele = 1.5 # typical station elevation
# 4. run_hyp
self.ztr_rng = np.arange(0,20,1)
self.p_wht = 0 # weight code
self.s_wht = 1
self.rms_wht = '4 0.3 1 3'
self.dist_init = '1 50 1 2'
self.dist_wht = '4 20 1 3'
self.wht_code = '1 0.6 0.3 0.2'
self.fhyp_temp = 'temp_hyp/temp_vp-pos.hyp'
self.pmod = 'input/example_p.cre'
self.smod = [None, 'input/example_s.cre'][0]
self.pos = 1.73 # provide smod or pos
```

# Write CRE Velocity Model

HK Model with $V_P/V_S$ Ratio of 1.73		
Depth to Top of Layer (km)	CRE Interfaces	$P$ -Velocity (km/sec)
0.0	0.0	5.5
5.5	6.5	6.3
16.0	17.0	6.7
32.0	33.0	7.8

# Weighting Scheme

- Distance weighting
  - $< \text{min\_dist}$ : full weight
  - $> \text{max\_dist}$ : zero weight
  - $\text{min\_dist} \sim \text{max\_dist}$ : cos taper
- Residual weighting
  - $< \text{min\_res}$ : full weight
  - $> \text{max\_res}$ : zero weight
  - $\text{min\_res} \sim \text{max\_res}$ : cos taper



Klein, 2014

```
self.ctrlg_code = 'eg_pal_hyp'
# 1. mk_sta: format station file
self.fsta = 'input/example_pal.sta'
self.lat_code = 'N'
self.lon_code = 'W'
# 2. mk pha: format phase file
self.fpha = 'input/eg_pal.pha'
# 3. sum2csv: format output files
self.ref_ele = 2.5 # ref ele for CRE mod (max sta ele)
self.grd_ele = 1.5 # typical station elevation
# 4. run_hyp
self.ztr_rng = np.arange(0,20,1)
self.p_wht = 0 # weight code
self.s_wht = 1
self.rms_wht = '4 0.3 1 3'
self.dist_init = '1 50 1 2'
self.dist_wht = '4 20 1 3'
self.wht_code = '1 0.6 0.3 0.2'
self.fhyp_temp = 'temp_hyp/temp_vp-pos.hyp'
self.pmod = 'input/example_p.cre'
self.smod = [None, 'input/example_s.cre'][0]
self.pos = 1.73 # provide smod or pos
```

# HypolInverse Output

- Catalog: *eg\_pal\_hyp.ctlg*
  - format: ot, lat, lon, dep, mag
- Phase: *eg\_pal\_hyp.pha*
  - event line: ot, lat, lon, dep, mag
  - phase line: net.sta, tp, ts, s\_amp, p\_snr
- Phase with evid: *eg\_pal\_hyp\_full.pha*
  - event line: ot, lat, lon, dep, mag, evid
  - phase line: net.sta, tp, ts, s\_amp, p\_snr
- Quality control files: *.sum, \_good.csv, \_bad.csv*

# Run HypoDD

- Station file
  - same as PAL, just *cp* into *input/*
- Phase file
  - \_full.pha, output of HypoInverse
  - event line: ot, lat, lon, dep, mag, *evid*
  - phase line: net.sta, tp, ts
- Location parameters
  - ph2dt
  - hypoDD

```
self.hypo_root = '/home/zhouyj/bin'  
self.ctlg_code = 'eg_pal_ct'  
self.fsta = 'input/example_pal.sta'  
self.fpha = 'input/eg_pal_hyp_full.pha'  
self.dep_corr = 5 # avoid air quake  
self.ot_range = '20190704-20190707'  
self.lat_range = [35.45, 36.05]  
self.lon_range = [-117.8, -117.25]  
self.num_grids = [1, 1] # x, y (lon, lat)  
self.xy_pad = [0.06, 0.05] # degree  
self.num_workers = 5
```

***hypoDD*** -- A Program to Compute Double-Difference Hypocenter Locations

(*hypoDD* version 1.0 - 03/2001)

by

Felix Waldhauser

U.S. Geol. Survey  
345 Middlefield Rd, MS977  
Menlo Park, CA 94025  
felix@andreas.wr.usgs.gov

**Please read  
this document!**

# HypoDD Output

- Catalog: *eg\_pal\_ct.ctlg*
  - format: ot, lat, lon, dep, mag
- Phase: *eg\_pal\_ct.pha*
  - event line: ot, lat, lon, dep, mag
  - phase line: net.sta, tp, ts, s\_amp, p\_snr
- Phase with evid: *eg\_pal\_ct\_full.pha*
  - event line: ot, lat, lon, dep, mag, evid
  - phase line: net.sta, tp, ts, s\_amp, p\_snr
- Quality control files: *.ph2dt & .hypoDD (screen output)*



# Outline

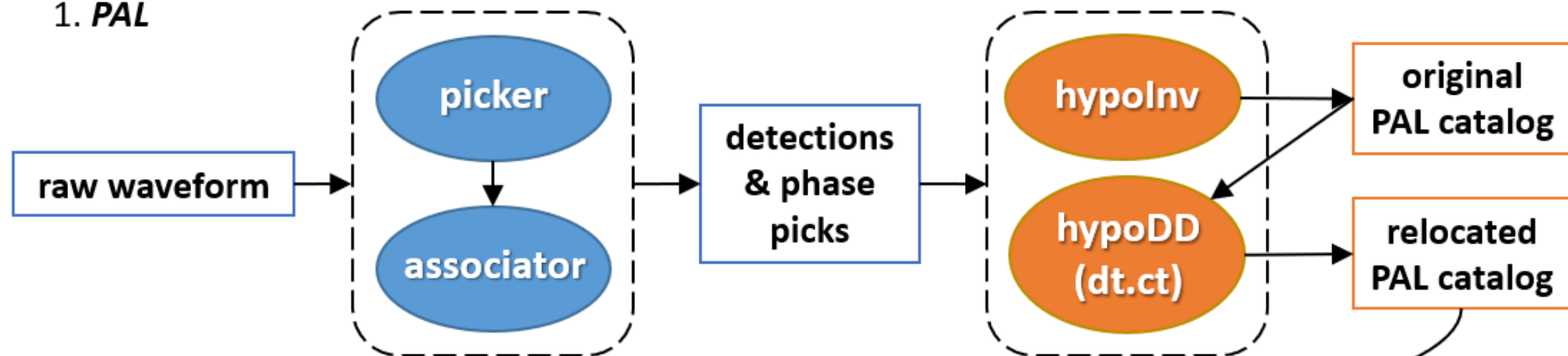
- Hardware & software
- Running PAL
- **Running MESS**

<https://github.com/YijianZhou/MESS/releases/tag/v2.3>

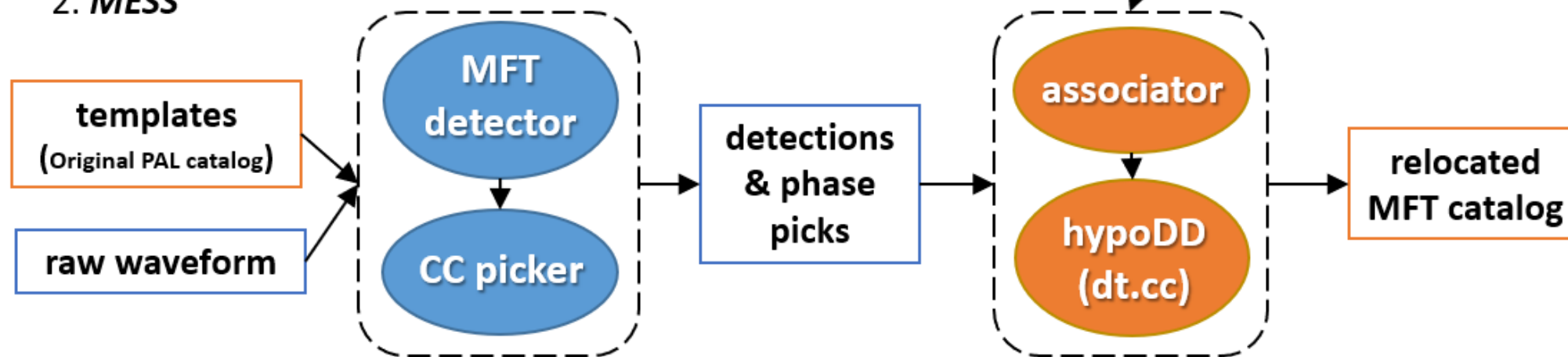
YijianZhou Update config.py		c1de740 4 days ago	🕒 183 commits
env	Update mess.yml	3 months ago	
example_mess_workdir	Update example.pha	last month	
hypodd	Update config.py	4 days ago	
README.md	Update README.md	4 months ago	
config.py	Update config.py	7 months ago	
cut_template_sac.py	update input format	7 months ago	
cut_template_torch.py	update input format	7 months ago	
dataset.py	Update dataset.py	22 days ago	
dataset_gpu.py	Update dataset_gpu.py	5 months ago	
mess_lib.py	remove jit for stability	5 months ago	
mess_lib_gpu.py	remove jit for stability	5 months ago	
run_mess.py	add CPU version	6 months ago	
run_mess_gpu.py	Update run_mess_gpu.py	4 months ago	



### 1. PAL



### 2. MESS

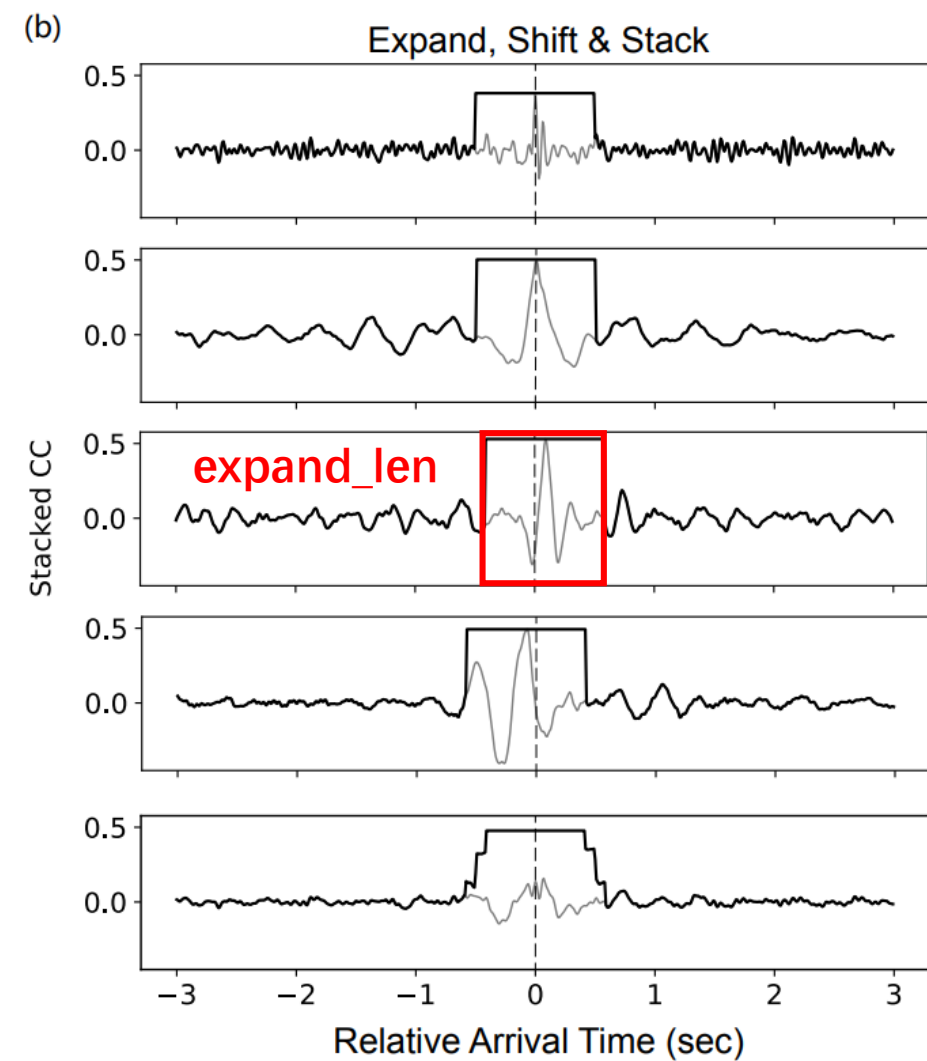
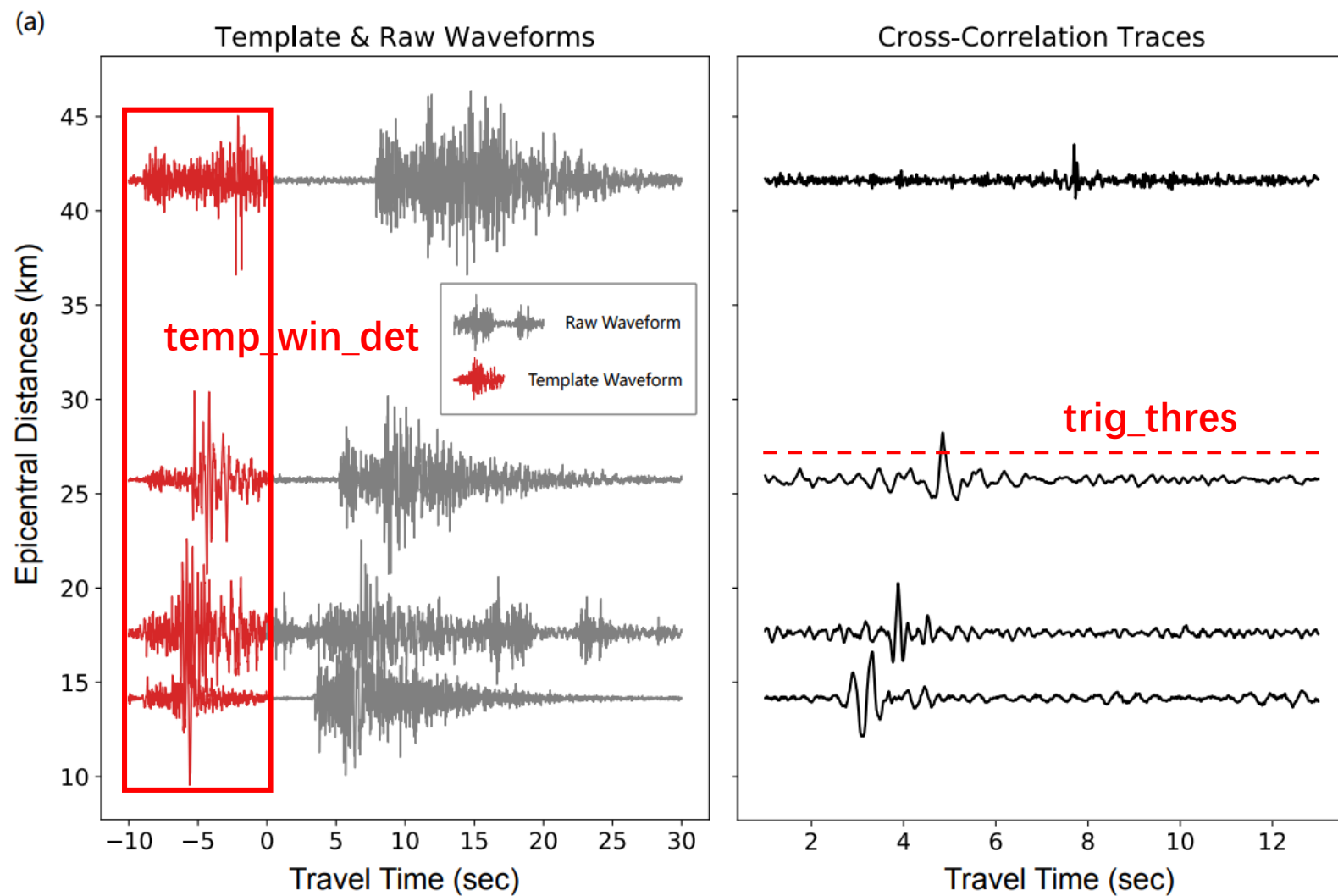


```

# MFT params
self.win_len = [10,20]
self.min_sta = 4
self.max_sta = 15
self.temp_win_det = [1.,9.]
self.temp_win_p = [0.5,1.5]
self.temp_win_s = [0.5,2.5]
self.trig_thres = 0.3
self.expand_len = 1.
self.det_gap = 5.
self.pick_win_p = [1.0,1.0]
self.pick_win_s = [1.6,1.6]
self.chn_p = [2]
self.chn_s = [0,1]
self.amp_win = [1,4]
# data process
self.samp_rate = 50
self.freq_band = [2.,40.]
self.num_workers = 10
self.get_data_dict = dp.get_data_dict
self.get_sta_dict = dp.get_sta_dict

# cut template length
# min sta num for template event
# max sta num for template event
# temp win for detection, pre & post P
# temp win for p pick, pre & post P
# temp win for s pick, pre & post S
# cc thres for det & peak expansion
# win len for cc peak expansion
# gap sec for detection
# search win for P pick
# search win for S pick
# chn for P pick
# chn for S pick
# win for amp measurement

```



Zhou et al., SRL 2021

```

# MFT params
self.win_len = [10,20]
self.min_sta = 4
self.max_sta = 15
self.temp_win_det = [1.,9.]
self.temp_win_p = [0.5,1.5]
self.temp_win_s = [0.5,2.5]
self.trig_thres = 0.3
self.expand_len = 1.
self.det_gap = 5.
self.pick_win_p = [1.0,1.0]
self.pick_win_s = [1.6,1.6]
self.chn_p = [2]
self.chn_s = [0,1]
self.amp_win = [1,4]
# data process
self.samp_rate = 50
self.freq_band = [2.,40.]
self.num_workers = 10
self.get_data_dict = dp.get_data_dict
self.get_sta_dict = dp.get_sta_dict

# cut template length
# min sta num for template event
# max sta num for template event
# temp win for detection, pre & post P
# temp win for p pick, pre & post P
# temp win for s pick, pre & post S
# cc thres for det & peak expansion
# win len for cc peak expansion
# gap sec for detection
# search win for P pick
# search win for S pick
# chn for P pick
# chn for S pick
# win for amp measurement

```

**Set MESS params based on the  
station distribution (average  
inter-distance etc.)**

# Running MESS

- Make template phase
  - PAL det phase: *eg\_pal.pha* → evid & event name
  - HypoInverse phase: *eg\_pal\_hyp.pha* → location
- Cut templates
  - *cut\_templates\_obspy.py*: if many events in one day
  - *cut\_templates\_sac.py*: if few events in one day
- Run MESS
  - use GPU version to enjoy ×40 acceleration
  - use CPU version if you have >100 cores cluster

# 1. Make Template Phase: *pha2temp.py*

- Inputs
  - Detection phase: *eg\_pal.pha*, providing evid & event name
  - Located phase: *eg\_pal\_hyp\_full.pha*
- Outputs
  - Template phase: *evid\_name, ot, lat, lon, dep, mag*

```
# i/o paths
fpha_det = 'input/eg_pal.pha'
fpha_loc = 'input/eg_pal_hyp_full.pha'
fout = open('input/eg_pal.temp', 'w')
# selection criteria
ot_range = '20190704-20190707'
ot_range = [UTCDateTime(code) for code in ot_range.split('-')]
lat_range = [35.5, 36.]
lon_range = [-117.8, -117.3]
```

## 2. Cut Templates

- Cut with Obspy slice: *cut\_templates\_obs.py*
  - read 1-sta 1-day's data & preprocess
  - slice all phases on that station & that day
- Cut with SAC cut: *cut\_templates\_sac.py*
  - for all events,
  - read ~30s event window & preprocess

**~100,000 events / ~1,000,000  
phases, finish with 20min**

```
# i/o paths
mess_dir = '/home/zhouyj/software/MESS'
data_dir = '/data/Example_data'
out_root = 'output/Example_templates'
temp pha = 'input/eg_pal.temp'
```



# 3. Running MESS

- Can start multiple processes based on the GPU memory
  - $n\_sta * 3 \text{ chn} * 4 \text{ bit} * 86400 \text{ sec} * \text{samp\_rate}$
  - $\rightarrow$  if 50Hz,  $100\text{M} * n\_sta$
- Can start multiple processes based on the CPU threads

```
# i/o paths
gpu_idx = '0'
mess_dir = '/home/zhouyj/software/MESS'
data_dir = '/data/Example_data'
time_range = '20190704-20190707'
sta_file = 'input/example_pal.sta'
temp_root = 'output/Example_templates'
temp_pha = 'input/eg_pal.temp'
```

```
template 0_20190704161342.98
15 detections, 10 stations, 0.8s
det_ot 2019-07-04T15:35:29.700000Z, det_cc 0.30
CI.TOW2 | dt_p -0.02s, dt_s -0.02s | cc_p 0.716, cc_s 0.744
CI.SRT  | dt_p -0.02s, dt_s 0.00 s | cc_p 0.395, cc_s 0.410
CI.CCC  | dt_p -0.02s, dt_s -0.02s | cc_p 0.378, cc_s 0.567
CI.MPM  | dt_p 0.00 s, dt_s 0.00 s | cc_p 0.849, cc_s 0.429
CI.JRC2 | dt_p 0.00 s, dt_s -0.02s | cc_p 0.334, cc_s 0.669
CI.CLC  | dt_p -0.02s, dt_s -0.02s | cc_p 0.558, cc_s 0.599
CI.SLA  | dt_p -0.56s, dt_s 0.00 s | cc_p 0.370, cc_s 0.382
CI.LRL  | dt_p 0.40 s, dt_s -0.02s | cc_p 0.265, cc_s 0.280
CI.WBM  | dt_p -0.22s, dt_s -0.90s | cc_p 0.255, cc_s 0.208
```

# HypoDD Relocation

- Relocate templates (*pal\_ct\_full.pha*)
- Relocate MESS detections: *python run\_hypoDD.py*
  - associate detections from different templates → *dt.cc*
  - run hypoDD (relocate with *dt.cc*)

```
# 2. mk_dt
self.temp_pha = 'input/eg_pal_ct_full.pha'      # reloc template phase file
self.det_pha = 'input/eg_mess.pha'              # mess output phase file
self.ot_dev = 2.                                # ot diff for det assoc
self.cc_thres = [0.3,0.4]                       # CC thres for det & pick
self.dt_thres = [0.6,1.]                       # max dt_p & dt_s
self.nbr_thres = [2,30]                        # min & max num of neighbor event
self.min_sta = 4
# 3. reloc2csv
self.lat_range = [35.4,36.1]
self.lon_range = [-117.85,-117.25]
self.xy_pad = [0.046,0.037]                   # degree
self.num_grids = [1,1]                        # x,y (lon, lat)
```

# MESS Output

- “Phase” output: *mess.pha*
  - fpath: out\_root/phase\_yyyymmdd-yyyymddd.dat
  - event line: evid\_name, lat, lon, dep, cc
  - phase line: net.sta, tp, ts, dt\_p, dt\_s, s\_amp, cc\_p, cc\_s
- HypoDD output catalog: *mess\_cc.ctlg*
  - format: ot, lat, lon, dep, mag

# Summary

- Prepare data
  - consistent directory structure → whether modify *data\_pipeline.py*
  - plot station location → reselection of station & tune PALM parameters
- Run PALM
  - rewrite file & directories
  - inspect detection and location results

# Remaining Topics

- Complex network configuration
- Tuning detection parameters
- Tuning location parameters
- Combination of different modules
- Special datasets (e.g. dense array, OBS, DAS etc.)
- .....

# References

- **Zhou, Y.**, H. Yue, L. Fang, S. Zhou, L. Zhao, & A. Ghosh (2021). An Earthquake Detection and Location Architecture for Continuous Seismograms: Phase Picking, Association, Location, and Matched Filter (PALM). *Seismological Research Letters*. doi: <https://doi.org/10.1785/0220210111>
- **Zhou, Y.**, A. Ghosh, L. Fang, H. Yue, & S. Zhou (2021, *in preparation*). Early Aftershock Catalog of the 2019 Ridgecrest, California Earthquake: Application of an AI-based Detection and Location Architecture. *Geophysical Research Letters*.
- **Zhou, Y.**, H. Yue, Q. Kong, & S. Zhou (2019). Hybrid Event Detection and Phase-Picking Algorithm Using Convolutional and Recurrent Neural Networks. *Seismological Research Letters*; 90 (3): 1079–1087. doi: <https://doi.org/10.1785/0220180319>
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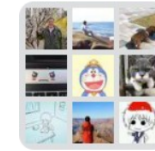
**Include but not  
limited to:**  
**Report bugs**  
**Assistance in usage**  
**Cooperation**  
**Technical discussion**  
... ..

周一剑 Yijian ZHOU

Email: [yijian.zhou@email.ucr.edu](mailto:yijian.zhou@email.ucr.edu)

WeChat: zhouyj\_observer

Github: <https://github.com/YijianZhou>



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