# Addressing Precision Limitations in the Seismic Analysis Code (SAC) File Header and Data Format

**SAC format is 20+ years old. Precision in timing and (perhaps) distance has improved beyond the SAC single-precision capability.**

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# Abstract

Twenty years ago, a time precision of 0.0 1s and a distance precision of parts of a km were acceptable limits, and 16 bits was the upper limit for most data acquisition precision. Now, thanks to GPS and other technologies, timing precision of ms and distance precision to meters are commonly used, and 24 bit digitizers are the norm. However, the header and data format for SAC files are unchanged: time, distance, and data are all single precision. As an example of reported shortcomings in SAC precision, the maximum number of seconds for which single precision will retain 1 ms precision is 16,384 seconds (4.5 hours). In addition, the IRIS DMC has stated a need to store amplitude data as double precision. Increasing precision in one or more variables has costs: a one-time cost in programming within SAC, and the problem of backward compatibility with programs using the current SAC file format. Examples of questions we need to address are the following: Presumably, a version of SAC with higher precision should be able to read old-format SAC files, but should that version be able to write files in the old format? Which variables should get increased precision? Should data in either single or double precision be an option? How cross-compatible should the SAC-IO Library routines be?

# Outline

- Current (Version 6) SAC Header
- Precision Primer
- Which variables to promote
  - timing?
  - distances and geographic variables?
  - amplitude?
  - blackboard variables? (separate from SAC format)
  - Internal calculations? (separate from SAC format)
- Implementation Considerations
  - Backward compatibility
  - Coordination with other programs that use SAC format
  - I/O routines
- How do we proceed?

# Current (v6) SAC Header

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0-7 | delta | depmin | depmax | scale | odelta | b | e | o |
| 8-15 | a | fmt | t0 | t1 | t2 | t3 | t4 | t5 |
| 16-23 | t6 | t7 | t8 | t9 | f | resp0 | resp1 | resp2 |
| 24-31 | resp3 | resp4 | resp5 | resp6 | resp7 | resp8 | resp9 | stla |
| 32-39 | stlo | stel | stdp | evla | evlo | evel | evdp | mag |
| 40-47 | user0 | user1 | user2 | user3 | user4 | user5 | user6 | user7 |
| 48-55 | user8 | user9 | dist | az | baz | gcarc | sb | sdelta |
| 56-63 | depmen | cmpaz | cmpinc | xmin | xmax | ymin | ymax | unused |
| 64-71 | unused | unused | unused | unused | unused | unused | nzyear | nzjday |
| 72-79 | nzhour | nzmin | nzsec | nzmsec | nvhdr | norid | nevid | npts |
| 80-87 | nsnpts | nwfid | nxsize | nysize | unused | iftype | idep | iztype |
| 88-95 | unused | iinst | istreg | ievreg | ievtyp | iqual | isynth | imagtyp |
| 96-103 | imagsrc | unused | unused | unused | unused | unused | unused | unused |
| 104-111 | unused | leven | lpsol | lovrok | lcalda | unused | kstnm | |
| 112-119 | kevnm | | | | khole | | ko | |
| 120-127 | ka | | kt0 | | kt1 | | kt2 | |
| 128-135 | kt3 | | kt4 | | kt5 | | kt6 | |
| 136-143 | kt7 | | kt8 | | kt9 | | kf | |
| 144-151 | kuser0 | | kuser1 | | kuser2 | | kcmpnm | |
| 152-159 | knetwk | | kdatrd | | kinst | | | |

single
real*4
4 bytes

int
integer
4 bytes

Character
Strings

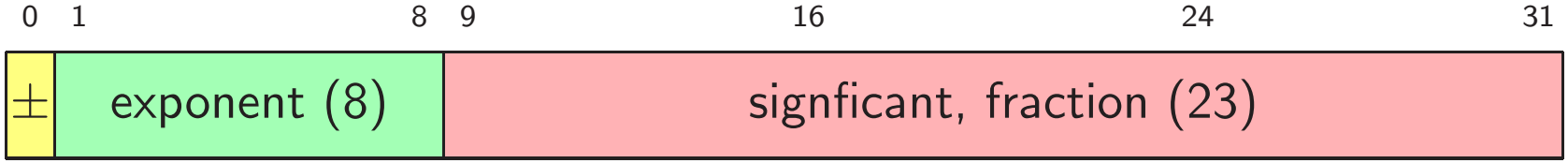
Size: $158 \text{ words} * 4 \text{ bytes/word} = 632 \text{ bytes}$

Variables labeled "unused" are inaccessible.

# SAC Header

- If we promote some variables to double precision, where should they be placed?
- **Header variable nvhdr indicates the byte-order of the file**
- Several variables are not used within SAC but are available to be used. 18 4-byte values are inaccessible.
- Version 6 header organized by variable type:
  - 70 4-byte reals — last 7 are unused;
  - 40 4-byte integer in groups including 11 unused;
  - 192 bytes containing 22 8-byte character strings and 1 16-byte character string.

# Precision Primer for Single Precision




- All reals in header/data are single-precision (32 bits; 4 bytes)
- For single-precision numbers, 23 bits define the maximum precision. All numbers between $2^{n-1}$ and $2^n$ have precision, DELTA, given by

$$\mathrm{DELTA} = \frac{2^{n-1}}{2^{23}}$$

  - ☛ If n $= 14$, $2^n = 16,384$, and DELTA $= 0.000976$.
  - ☛ If n $= 17$, $2^n = 131,872$, and DELTA $= 0.00781$.

# Timing Precision

20 years ago, a sampling rate of 0.01 s was probably sufficient. Now thanks to GPS and other advances, many experiments require sampling rates of 0.001 s.

- For DELTA to be less than 0.01 s, the total time must be less than 131,872 s = 1.5 days (n = 17)
- For DELTA to be less than 0.001 s, the total time must be less than 16,384 s = 4.5 hours (n = 14)

Times within SAC are defined relative to a reference time. Timing variables are b, e, o, a, f, t0–t9 — 15 variables. If one is promoted, all must be. The smallest time increment within SAC I/O is 0.001 s (header variable nzmsec is milliseconds).

# Distance and Geographic Variables Precision

It is now possible to measure locations to within meters.

- To the nearest meter, the maximum longitude is 179.9999.
  **The precision for latitudes/longitudes is $\leq 0.2$ m.**
  That is marginally okay for one-meter precision.
- Half the circumference of the Earth is about 20,000 km. The precision for this distance is about 2 m, but a bigger limitation for large distances is the precision of the reference ellipsoid.
- Header variables eval, evlo, stla, and stlo are the prime candidates for promotion; Variables dist, az, baz, and gcarc would not need to be promoted.
- Relative positions require less precision than absolute position within SAC.

## Amplitude Precision

- 20 years ago, 16 bits was the standard for data.
- Today 24 bits is standard. $2^{24} = 16,777,216$.
  - Precision of about 1.0
- **With current instrumentation, higher precision is not required.**

## Maximum Number of Points

- Integer header variable npts has 4 bytes (32 bits).
  - Maximum is 2,147,483,647 (unsigned 4,294,967,296)
  - **If sampling rate is 0.001 s, maximum record length for 32 bits is 24.8 days.**

# Developers' Current Thoughts on SAC Format

- Promotion of select values to double precision
  - Timing values **[Needed]**
  - Geographic values **[Marginally adequate]**
  - Amplitude values **[Not needed now]**
  - User values **[Probably some]**
  - Internal SAC **[Do all calculations in double precision]**
- Promotion of all header variables to double precision? **[No]**
- Header organization — still under discussion, but nvhdr offset must remain the same
- Promote blackboard variables to double precision

# Implementation Considerations

- Addresses precision problems with timing and time picks
- Promotion of header values will alter the SAC Format
  - Current version (v6) has remained unchanged for 20+ years
  - In version 7, some header variables will be double precision, so the header size will change and the data-start offset will accordingly change
- Proposed changes addresses reported problems with blackboard variables
- Programs that use SAC files will be affected
- SAC/IO routines must handle both v6 files and v7 files

# Conclusions

- Current SAC format limitations:
  - For high sampling rates and long record lengths, timing precision in SAC is inadequate
  - Geographic values are marginally adequate
  - Amplitude values are probably okay for now
- Promoting timing values addresses most immediate problems
- Increasing precision will change SAC header which has implications on existing programs that read/write SAC files as well as SAC I/O routines
- Developers are seeking feedback on these topics as well as how to handle backwards compatibility