Are we all in *concordance* with the meaning of the word *conformance*, and is our definition in *conformity* with standard definitions?

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Introduction

The term *conformance* is used widely in the geologic carbon sequestration (GCS) community to convey something about the sound understanding and performance of a GCS system. Yet I have often been confused by what exactly is meant by the term. My confusion arises for several reasons. First, the word *conformance* has accepted everyday definitions in English. Second, the term has a very specialized meaning in the reservoir engineering (oil recovery) context and that meaning also has relevance to GCS. Third, the term is very similar in sound if not meaning to two other words (*concordance* and *compliance*). Finally, there are inconsistencies in the definitions and usage of the term *conformance* within various GCS regulatory documents.

In this feature article, I summarize some of the various definitions of *conformance* and conclude with a recommendation on a GCS-specific meaning of the word including illustrative graphics to help communicate the proposed definition.

Standard English definition

The online Oxford English Dictionary[1] says *conformance* is another word for *conformity*which it defines first as “Compliance with standards, rules, or laws,” and fourth as similarity in form or type, i.e., agreement. The online Merriam-Webster dictionary[2] also prefers the word *conformity* to *conformance* and provides a first definition related to agreement or correspondence of one thing to another, and a third definition similar to the Oxford online dictionary related to compliance with standards, rules, laws. The two dictionaries provide standard everyday definitions that cause no problems in the GCS context despite the preference for *conformity* over *conformance* which they agree are synonyms.

ISO 9000 quality management systems definition

In the context of quality management, the international organization for standardization (ISO) provides a definition[3] for *conformity* (as a synonym and preferred term for *conformance*) as “fulfillment of a requirement” (see 3.6.11, or search (ctrl-f) at the footnoted URL). In this same quality management context, one can find the same ISO 9000 definitions in plain English.[4] Between standard English and ISO 9000 definitions, the term *conformance*is well-defined and relates to meeting standards or

requirements, although there is a preference to use the synonym, *conformity*.

Subsurface oil-recovery and fluid-injection definition

When reservoir engineers and other subsurface scientists familiar with two-phase flow in porous media hear the word *conformance* in a subsurface context, they usually think of one thing and that is the degree to which the injected fluid uniformly displaces the resident fluid. This definition is provided at PetroWiki[5] as follows:

“Conformance is a measure of the uniformity of the flood front of the injected drive fluid during an oil recovery flooding operation”

In other words, an injected displacing fluid that very evenly and without extensive fingering displaces the original fluid is referred to by reservoir engineers as having good *conformance*. Reservoir engineers often attempt various approaches to *conformance control* to mitigate poor *conformance*.

In many cases, a specialized definition of a term causes no confusion because it is confined to its special domain where the context makes the meaning clear. The situation for the term *conformance* related to subsurface contexts has no such clear boundary. The fact is that $CO_2$is a common injectate for enhanced oil recovery, therefore confusion about the meaning of *conformance* arises because one would not know if the term was referring to displacement characteristics or to meeting a regulation or standard related to CO_2 injection.

European Union (EU) CCS transfer of liability definition

Under the EU liability-release part of the CCS regulatory directive,[6] there exists the following text:

“The operator's report

As part of this, the operator must prepare and submit a report showing that the site has met the requirements in point (a) above. This document must demonstrate at least three points:

- i the conformity of the actual behaviour of the injected CO_2 with the modelled behaviour;
- ii the absence of any detectable leakage; and
- iii that the storage site is evolving towards a situation of long-term stability.”

The above quoted text implicitly assigns a meaning to *conformity* as being agreement between modeled (forecasted) behavior and actual (monitored or measured) behavior. I believe this usage of the term *conformance/conformity* is common in the research community, which is confusing because such usage overlaps with the term *concordance* (see

below). At another place in the same EU document[6] (use crtl-f to search) *conformity* is used with the standard English definition.

Existing word for agreement between models and observations

Usage of the word *conformance* to mean agreement between model results and observations is distracting as noted above because there is already a very similar word, *concordance*, with this same meaning.[8] Briefly, in statistics or mathematics, the agreement between quantities from two datasets can be plotted on an x-y graph. The degree to which values on such a graph lie on a straight 45-degree line are measures of *concordance*. In the GCS context, we often plot the observations (actual values) on the y-axis and the model forecasts on the x-axis. Deviations from perfect *concordance* can be quantified using *Lin's concordance correlation coefficient*.[7] *Concordance* by this definition is not a binary yes or no determination but rather is quantifiable and variable and can range from excellent to poor over different ranges of observation values. This use of the term *concordance* fits very nicely in the GCS field because geologic uncertainty and heterogeneity, not to mention complexity of flow processes, can lead to uncertainty and ranges of results on the model results axis of the *concordance* plot, while measurement approaches and instrumentation also lead to uncertainty on the observation axis. In short, *concordance* is not usually black and white but rather needs to be qualified using terms such as *acceptable* when agreement is within a quantifiable envelope of acceptability.

One point to mention here is the possibility that multiple models can match observations, i.e., the lack of uniqueness in history matching. For the purposes of this discussion, I am assuming modeling is being carried out by competent groups and, even if non-uniqueness in the modeling is present, e.g., similar results are obtained by very different competing models, the models can defensibly simulate mechanistic aspects of system behavior. With this caveat, history matching is assumed here to imply that the model(s) used have a forecasting capability reflecting their ability to simulate the applicable physical processes as demonstrated by their ability to match prior behaviors and performance.

Definition from the government of Alberta

The government of Alberta, Canada, has published a summary report of its regulatory framework for CCS[7] and includes the following among its recommendations for closure requirements (see pg. 60):

“a) Sequestered CO_2 and affected fluids are conforming to the objectives and regulatory requirements as described in the project application and approvals.”

So in the above instance Alberta has used a meaning for *conformance* in agreement with standard English. The Alberta regulatory summary also includes a glossary and this is where *conformance* is equated with *concordance* as follows (footnote 8, pg. 131):

“Conformance: the degree to which the sequestered CO_2 behaves as predicted, as informed by monitoring. For example, demonstration of conformance could include:

• Output from models match monitored data within acceptable limits, and the need to modify static and dynamic model parameters has been systematically reduced over a certain time period.

• Final models are within acceptable confidence limits of the history match. Where the time period and acceptable limits are developed based on a technical assessment of comprehensive site and project data.

Monitoring, measurement and verification (MMV): monitoring and measurement are surveillance activities necessary for ensuring the safe and reliable operation of a CO_2 sequestration project. Verification refers to the comparison of measured and predicted performance, which is also known as conformance.”

As shown, within the Alberta regulatory language, *conformance* takes on either the standard English definition or the definition synonymous with *concordance*.

Definitions from the management systems field including the word *compliance*

The distinction between the terms *conformity* (synonym of *conformance*) and *compliance* is addressed at the website of Whittington Associates,[9] a management systems consulting firm. They provide the following paragraph (after reviewing the same ISO 9000 recommendations quoted above that prefer *conformity* to *conformance*):

“Conformity can be viewed as internally driven, such as our voluntary, consensus-based standards. *Compliance* can be viewed as externally imposed. So, we should use *conformity*, not conformance or compliance, when referring to fulfilling product and process requirements. Of course, if customers impose conformity to ISO 9001, your organization may feel like it has to *comply* rather than *conform*.”

By this definition, the term *compliance* is preferred over *conformance* in the context of a GCS project meeting or exceeding externally imposed requirements as embodied in law, in regulations, or even in customer requirements. And by their definition, a GCS project operator would be in conformance if it meets internally set standards and/or best practices. Because this distinction to me is secondary to improving clarity of the use of the term *conformance*, I will not discuss differences between *conformance* and *compliance* further nor make any recommendation in this regard.

Recommendations for *conformance* in the GCS context

As discussed above, there are several similar terms being used in standard ways and specialized ways both in the GCS community and in other contexts.

I would like to recommend consideration of a more well-defined meaning for the term *conformance* in the GCS context. First, regarding *conformance* vs. *conformity*, there is good reason to retain the term *conformance*. The main reason is that the term is already in use in the GCS community including in written documents, and it seems easier to tighten or refine the definition than to throw it out altogether. The second reason *conformance* is strongly preferable to *conformity* is that the lack of *conformance*, i.e., *nonconformance*, would be called *nonconformity* which has a very specific and totally different meaning in geology.[10]

In the GCS context, the main components implied by the term *conformance* are in the areas of model agreement with observations and system *performance* where *performance* encompasses CO_2 containment in line with design parameters such as injectivity and capacity along with acceptable environmental impacts, e.g., in the areas of induced seismicity and impacts on potable groundwater. Therefore, it makes sense to combine model agreement with observations (i.e., *concordance*) and *performance* as two necessary conditions for *conformance*. I note the same logic was used by Chadwick and Noy in their 2015 article in *Greenhouse Gases*[11] in which they proposed the need to combine *performance* measures with quality modeling forecasts to make a case for *conformance*. Considering all of the above, the following definition naturally arises:

Conformance of a GCS system is the condition under which there is acceptable *concordance* and acceptable *performance*. This definition can be shown by the Venn diagram of Fig. 1.

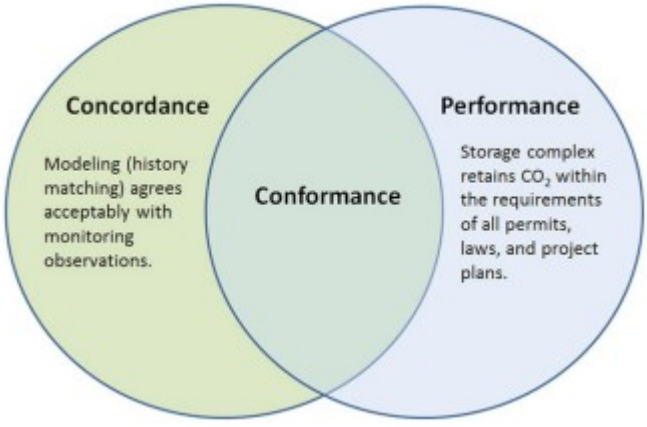

Figure 1

Venn diagram showing the requirements of *conformance*, namely acceptable *concordance* and *performance*.

The words *concordance* and *performance* by themselves rely on agreement with observations and so are only relevant in the past or present tenses, as in, “…the GCS system has been and continues to be in *conformance* by virtue of excellent *concordance* with models and *performance*, both of which are constrained by the measurements from an effective monitoring system.”

But *performance* can be forecasted using models, and therefore an element of prediction is possible. Specifically, a defensible forecast of continued acceptable *performance* along with a history of acceptable *conformance* should allow a *forecast of conformance*. This definition is shown by the diagram in Fig. 2.

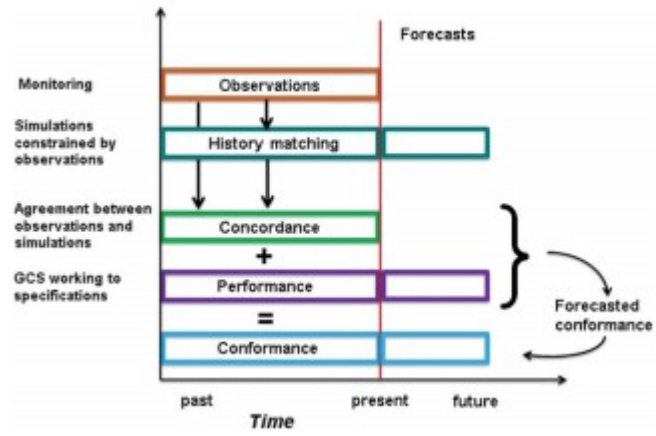

Figure 2

Temporal aspects of *concordance*, *performance*, and *conformance*. A forecast of acceptable *performance* along with acceptable prior and current *conformance* allows a *forecast of conformance*.

I welcome ongoing discussion of these definitions of *conformance* and *forecasted conformance* as the GCS community strives for clarity and consistency in its internal and external communications.

Acknowledgements

I thank Robert J. Budnitz (Lawrence Berkeley National Laboratory), Andy Chadwick (British Geological Survey), and Jonathan Ennis-King (CSIRO) for helpful insights and editorial comments. I also thank my colleagues with the National Risk Assessment Partnership (NRAP) program Robert Dilmore and Nicolas Huerta (National Energy Technology Laboratory (NETL)), and Elizabeth Keating and Dylan Harp (Los Alamos National Laboratory (LANL)) for discussions and comments that tightened the proposed definitions. This work was supported by the NRAP project funded by the U.S. Department of Energy (DOE) Fossil Energy Program Office through its CO_2 Sequestration R&D Program managed by NETL. Additional support was provided by Lawrence Berkeley National Laboratory with funding from the U.S. DOE Office of Science under Contract No. DE-AC02-05-CH11231.

References

1. https://en.oxforddictionaries.com/definition/conformance 2. https://www.merriam-webster.com/dictionary/conformance 3. https://www.iso.org/obp/ui/#iso:std:iso:9000:ed-4:v1:en 4. http://www.praxiom.com/iso-definition.htm#Conformity 5. http://petrowiki.org/Conformance_improvement 6.

https://hub.globalccsinstitute.com/publications/ccs-liabilitylegislation/liability-under-european-ccs-directive-storage-CO2 7. https://en.wikipedia.org/wiki/Concordance_correlation_ coefficient 8. http://www.energy.alberta.ca/CCS/pdfs/CCSrfaNoAppD.pdf 9. https://www.whittingtonassociates.com/2002/06/conformityconformance-or-compliance/ 10. http://www.glossary.oilfield.slb.com/Terms/n/nonconformity.aspx 11. Chadwick A, Noy D, Underground CO2 storage: demonstrating regulatory conformance by convergence of history-matched modeled and observed CO2 plume behavior using Sleipner time-lapse seismics. Greenhouse Gas Sci Technol. 5:305–322 (2015); https://doi.org/10.1002/ghg.