Workflows in

Mechanistic Geosystems Analysis

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Relevance | Motivation

„Energy and Heat Transition“

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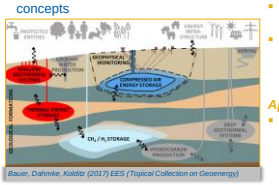
- **Solid Earth**: Origin of minerals, fossil fuels, water, rocks and soil
- **Geosystems**: Sufficient and safe space for energy storage and waste repositories
- **Competition|Synergies** in usage concepts



Bauer, Dahmke, Kolditz (2017) EES (Topical Collection on Geoenergy)

Challenges

- Large **storage** capacities for surplus energies from fluctuating renewables (Power to X technologies, 100+ TWh/a,)
- Safe **repositories** to deposit energy waste,
- “**Heat Transition**” (50% primary demand): Geothermal systems for urban supply
- **Need**: Scientific methodology and knowledge-based tools for assessment of suburface usage concepts: feasibility, decision making, legislation, environmental impacts

Approach

- Developing and providing a **unified mechanistic framework** for a comparative evaluation of different geotechnological options

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Framework

OpenGeoSys Workflows

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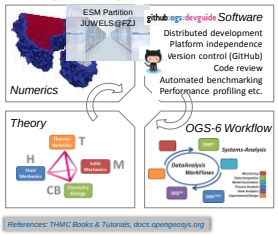
Our Credo: *Combining Geosciences and Information Technology for a new generation of scientific codes*



Theory

- First Principles, Theory of Porous Media
- Coupled fluid # solid mechanics and reactive transport processes (THM/CB > PDEs)

Numerics

- FEM: Tailored for fractured-porous media and coupled problems

Software

- Professional software engineering (> Poster)
- Designed for new HPC technologies (hybrid)

OGS-Workflows

- Data integration # numerical engine # visual data analytics
- Open source project with almost 30 years experience (permanent renovation)

References: THMC Books & Tutorials, docs.opengeosys.org

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OpenGeoSys Workflows

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Use case

- Rapid project work
- On demand

Development

- OGS DataExplorer
- OGS Visualization pipelines

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Operational Geosystems Modeling

Geoenergy Applications in Northern Germany

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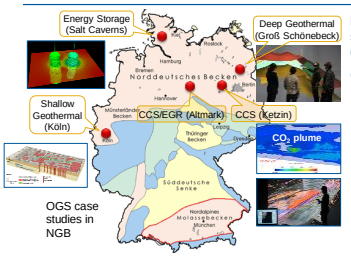

North-German-Basin (NGB): Real-scale test bed for Germany's various geoenergy applications

Operational Models

- CO_2 storage: Ketzin
- Enhanced Gas Recovery: Altmark
- Enhanced Geothermal Systems: Groß Schönebeck (Poster session)
- Energy Storage: Salt caverns
- Shallow Geothermal (Poster session)

Transferable Models

Earth System Knowledge Platform (ESKP): www.eskp.de > Energy Transition & Environment

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Generic Workflow Concept

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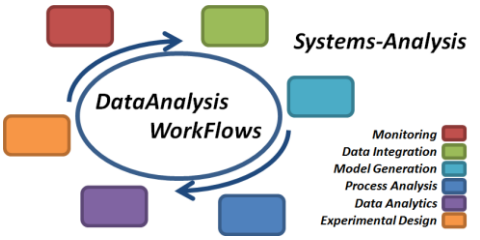

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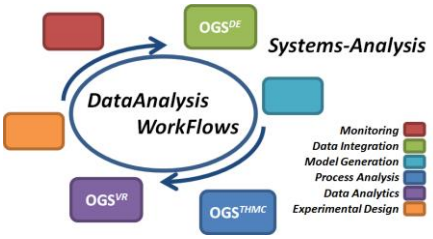
Generic Workflow Concept



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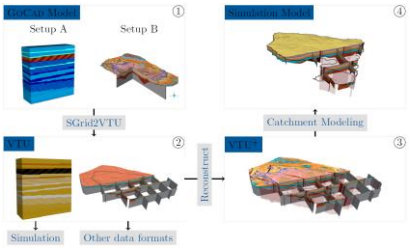
Generic Workflow Concept: Topology



Methods

- Geometric objects
- Structured meshing (hyperresolved)
- Unstructured meshing
- VTK interface

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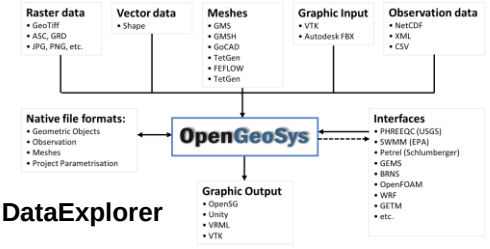
Generic Workflow Concept: Interfaces



DataExplorer

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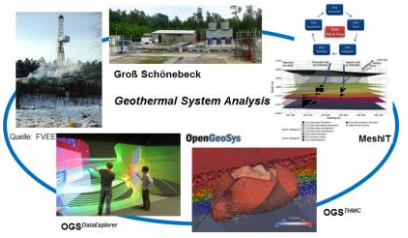
Workflow Applications: Geothermal Energy



Challenges

- Geometric objects
- Unstructured meshing
- THM coupled analysis

Example #1

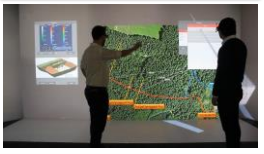
Enhanced Geothermal Systems (EGS)

Challenge

- Fully coupled THM model including all important reservoir elements (sediment layers, faults) and geotechnical features (wellbores, hydro-fracs)

THM

Geothermal reservoir simulation – EGS Groß Schönebeck



Achievements and Future Work

- **Reservoir efficiency**: 2nd production wellbore essential for long-term heat extraction
- **Reservoir evolution**: Wellbore distance and local stress field orientation are equally important (THM effects)
- **Hydrogeochemistry**: Clogging effects are crucial > understanding of THMC processes

Partner

GFZ KIT

Watanabe et al. (2018) SpringerBriefs; Jacquey, Watanabe et al. (2016)Tectonophysics; Blöcher, Watanabe et al. (2015) Comput. Geosci.

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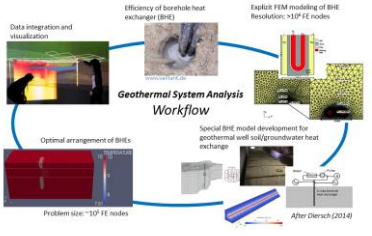
Workflow Applications: Geothermal Energy



Challenges

- Conceptual modeling (multi-continua approach)
- Coupling (monolithic)
- Borehole heat exchanger arrays
- Mechanics (THM): Freezing-thawing

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Workflow Applications: Geotechnics

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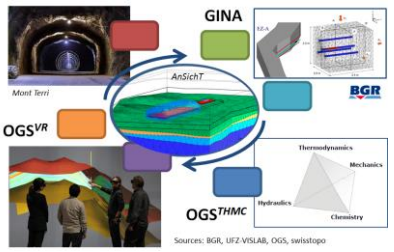

Sources: BGR, UFZ-VISLAB, OGS, swisstopo

Application areas

- CO2 storage
- Energy storage
- Waste deposition

Challenges

- HPC for field site applications
- Mechanics: new constitutive models of energy storage – frequent cycling loading / unloading

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Example #2:

Carbon Capture Storage (CCS)

(T)H²M

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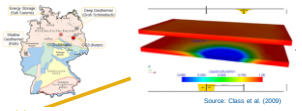
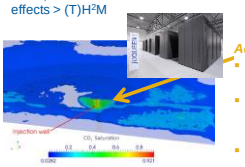
Challenges

- Reservoir models for CO_2 storage sites (Ketzin and Altmark) including multi-phase flow and deformation effects > (T)H²M



Source: Class et al. (2009)



Achievements

- Systematic **benchmark** studies for CO_2 storage (CO2BENCH) > extension to 3D
- **Physics**: Density effects in multiphase flows (sc CO_2 and brines) important for early arrival time calculation
- **Computation**: HPC methods are essential for field scale applications

Partner: GFZ, BGR, JÜLICH

*References: **Park, Böttcher** et al. (2012) Comp. Phys.; **Kolditz** et al. (2012) CO2BENCH, EES; McDermott, **Wang** et al. (2016) Greenhouse Gas Control*

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Example #3:

Cavern Energy Storage

(T)HM^in

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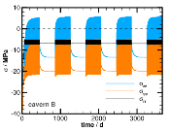
Challenges

- Entire life cycle of cavern
- Realistic cavern geometries
- Typical operation scenarios (frequencies) analyzed

VIS: Interactive operations with objects



Achievements and Future Work

- Newest constitutive salt models for cyclic processes implemented (IfG cooperation)
- Certain operation modes can lead to failure
- Cavern arrays are required for more frequent charging/discharging > interaction

Partner: CLAUSTHAL, IfG, BGR

*References: **Böttcher, Nagel** et al. (2017) EES (ANGUS+ Topical Collection); **Nagel**, Minkley, **Böttcher** et al. (2017) Comput. Struct.*

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Example #4:

Technical Energy Storage

T²HC²

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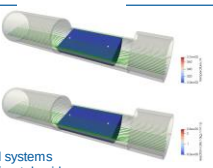
Challenges

- High-temperature energy storage (1200°C)
- Extensions for local thermal non-equilibrium processes
- Reactor, material and process to be designed in unison



Kerskes et al. (2012)

Achievements

- Novel composite material systems numerically investigated (metal-oxides, zeolites)
- Models greatly reduced experimental effort
- OGS - reference model for other groups

Partner: DLR, UNIVERSITÄT LEIPZIG

*References: **Lehmann, Nagel** et al. (2017) Appl. Energy; **Semprini**, **Nagel** et al. (2017) Energy Conv. Manag.; **Nagel** et al. (2016) Review, Appl. Energy*

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Framework OGS

Documentation | Knowledge Transfer

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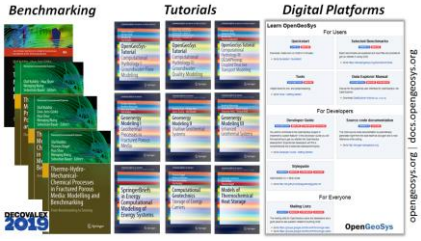
Benchmarking ***Tutorials*** ***Digital Platforms***



Knowledge & Technology Transfer

-

Regular Training Courses and Community Meetings

References: THMC Books (vol. 4 dedicated to DECOVALEX) & Tutorials, docs.opengeosys.org

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Subunit: Geosystems Modeling

Outlook & International Activities

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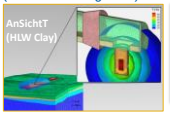
Nuclear Waste Management:

- Feasibility of different host rock types (unified frameworks)
- Concepts for near and far field modeling
- Reactive transport processes (radionuclide migration)



International Activities

- Mexico: Superhot geothermal systems
- China: Urban heating/cooling supply

*References: **Parisio, Nagel** et al. (2018) NSR; **Lu, Shao** et al. (2018) JGR-Solid Earth (submitted)*

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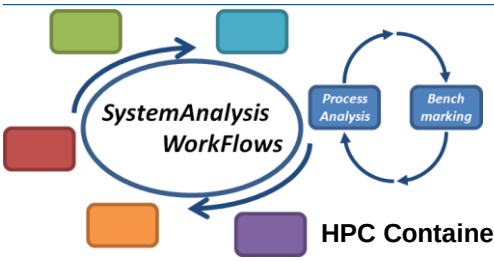
Framework

Workflows: Outlook



HPC Container

Thank you for your attention