Reports from Breakout Session IV (yesterday late afternoon)

Links to industry, natural resources and the environment

What are the key scientific questions?

Can we improve imaging of reservoirs and host rock/structures, including time-dependent imaging?
How can we recover attributes (porosity, pressure, state of stress etc.) from geophysical observations?
Can we constrain composition and movement of fluids (aqueous and non-aqueous) in the subsurface?

What are the impacts of fluid injection/removal from the subsurface (e.g., seismicity and subsidence)?
How do we determine the integrity of containment?

How can we identify what areas are most susceptible to induced seismicity?
Are the rupture processes & ground motion from induced earthquakes different from natural EQs?
How will climate change affect infrastructure (e.g., permafrost, extreme weather events, gas hydrate dissociation, etc.)?
What are the best approaches to evaluate and mitigate threats to major

Links to industry, natural resources and the environment

What are the key scientific questions?

How does the thickness of soil and regolith vary at the landscape scale, how do these variations influence water storage capacity, and what controls those variations?

What defines and controls the base of the critical zone?

How can we best observe (and separate from other signals) all components of total water storage and their fluxes, at all spatial and temporal scales? (e.g., soil moisture, vegetation, surface water, snowpack, groundwater and linkages between them)

Links to industry, natural resources and the environment

What foundational facilities are needed?

Existing monitoring arrays (GSN, USNSN, regional arrays)
Broadband and intermediate-period, portable seismometers

Continued access to a marine, crustal-scale, active-source seismic reflection/refraction facility

InSAR capabilities
GPS

Existing portable MT instrument facility

Data management and distribution center

Internships and educational opportunities (training etc.) for geoscience students

Links to industry, natural resources and the environment

What frontier facilities are needed?

- Large N arrays of 3-component sensors for short-term deployments that will serve both active-source and passive-source community
- Large N arrays of wide-band MT/Controlled Source EM land and marine instruments
- Ground-based true aperture interferometric radar
- National facility for near-surface geophysical instrumentation
- Access to land reflection facilities, including crustal-scale source capabilities
- Community Infrasound equipment
- Improved access to boreholes and downhole sensors and data
- Rapidly deployable airborne and rapidly taskable space-borne instrument platforms for EM and potential fields

Links to industry, natural resources and the environment

What frontier facilities are needed?

- A rapid-response, telemetered facility for induced seismicity
- A rapid-response facility for environmental events
- Multiple order of magnitude increase in our data management capabilities
- Expanded summer internships in collaboration with industry (e.g., building on and supporting the Summer of Applied Geophysical Experience field course in near-surface geophysics)
- MOOCs in geophysical concepts to bridge between academia and industry
- Access to an active injection well to study induced seismicity.
- Opportunities for interagency collaborations to access *in situ* wells and test sites

Links to industry, natural resources and the environment

How do facilities relate to broader impacts?

Increased data sharing with industry (bi-directional)
Best practices for monitoring
Best practices for siting injection wells
Facilitate interactions between academic scientists, government, industry and policymakers

Stronger collaboration with industry in masters and post-graduate opportunities
Stronger collaboration with industry in workforce development at all degree levels
Provide opportunities that attract students into the geosciences
Identify and exploit overlap between resource issues and hazards

Large N arrays, arrays of arrays
- record full, spatially less aliased wavefields

<u>Science Questions that can be addressed with less spatially aliased wavefields</u>

Improved Resolution of Structure/Dynamics:

Planet Scale

- targeted studies of boundary layers such as transition zone, D'', outer/inner core
- Understanding sources of earth's "hum" (200+ sec)

Mantle

- targeted studies of subducting plates (structure and dynamics)
- rheological nature of the LAB (whatever that is)
- Mid Lithosphere Discontinuities???
- Tracing of volatiles through the planet
- Improved understanding of metamorphism over a broad range of P/T space

Large N arrays, arrays of arrays
- record full, spatially less aliased wavefields

__Science Questions that can be addressed with less spatially aliased wavefields__

Improved Resolution of Structure/Dynamics:

Crustal

- Evolution of continental crust
  - higher resolution imaging of lateral variations in wavespeed and attenuation
  - intracrustal interfaces
  - crustal anisotropy
- magmatic evolution within the crust
- crustal deformation and links to mantle dynamics
- rheological layering
- Critical zone (for its own sake, and to correct for it)

High resolution images of magma reservoirs, 4D

Glaciers

- Better understanding of increasing rates of glacier margin migration
- 3D imaging of glacial structures to understand basal boundary conditions and
- distribution of sub-glacial water

Large N arrays, arrays of arrays
- record full, spatially less aliased wavefields

- **Other questions:**
- Understanding sources, Capturing a propagating rupture with strong motion sensors
- Fault zone structure illumination, Fluids in fault zones
- Induced seismicity, Microseismicity, Humming Fault? New types of seismicity?
- Non-tectonic source characterization (landslides, glacial calving, the ocean, rivers, extreme weather, flooding, microseism, debris flows)
- Separation of source and path effects of volcanic tremor
- Diverse glacial source characterization
- Source monitoring (nuclear)
- To better characterize the transition from anelastic behavior to the linear domain
- Effects of topography and 3D structure on wavefields - bias source strength estimates
- Better discrimination capabilities
- Strong ground motion / Hazards
- Microzonation - fine scale variations of strong shaking
- Soil-structure interactions (building - dirt bonding)
- Green('s) functions analyses of site effects

- Also noted, but covered by other break out groups: Resources, Geotechnical, environment, Teaching, Soils

Large N arrays, arrays of arrays
- record full, spatially less aliased wavefields

Foundational Capabilities

- Capabilities to record very very long period wavefields (GSN +)
- Capabilities to fully record wavefields at long periods (10s to 100s)
- Capabilities to fully record wavefields at short periods (10 Hz to 100 Hz)

Frontier Capabilities

- Capability to fully record wavefields at intermediate periods at 10 Hz to 10 seconds
- Large N Geodesy
- Strong motion sensors
- Storage capacity for these very very very large data sets
- In the oceans…. arrays (quasi permanent) at a range of bandwidths (up to very long periods) and spatial scales (small, regional, global)
- Cabled active source array systems
- Improved S/N with borehole (meters to km) sensors
- Large N in Depth!!
- Optic Fiber technology

GNSS/InSAR/LIDAR/etc: New technologies

Science Targets

- Big N geodesy for volcanos (ash & deformation could use different types/cost levels)
- Glaciology
- Sea Level
- Warning/Hazard Science
- Crisis Rapid Response
- Subsidence, Landslides, Sinkholes
- Hydrology
- Topographic change
- Earthquakes
- Interseismic deformation
- Off-fault deformation

GNSS/InSAR/LIDAR/etc: New technologies

Frontier: GPS

- Global Navigation Satellite System (GNSS: Assumed).
- Low cost, multi-frequency & low power systems: How cheap could they get (< $1000… <$25?). Quantity+Quality.
- Analysis methods: Some subtle network issues with precise point positioning (PPP); needs for processed results, greater need with new GNSS signals.
- In-receiver processing that preserves access to raw data through telemetry channels and consider range of abilities (flavors) for various applications.
- More choices on receiver cost, measurements, power, telemetry options.
- Better accuracy of SNR data (coded tracking)
- High-rate and/or low-latency. High temporal resolution.
- GNSS Reflection methods. Cheap antennas that don't suppress the ground reflections
  - applications to environmental including sea level
  - education would be needed to include the existing unavco community in antenna placement
- Telemetry needs to be robust, high-rate low-latency, networked, low power and inexpensive (like motes?)

GNSS/InSAR/LIDAR/etc: New technologies

Frontier: InSAR

- Data volume: 30 Gb images very 6-10 days
- Need strategies to cope with 24Tb/day (Petabyte/yr) from NISAR:
  - Greater temporal & spatial sampling (changing application space)
  - 3D with forward and backward looks & tandem SAR
- Centralized processing of interferograms
- Facility capability to provide computational/cloud environment to use/ interpret data (e.g. ARIA-like)
- Polarimetry
- Capability to image water, ice, snow, other surface conditions.
- Availability of the processed images (in time series) e.g. deformation and damage mapping rapidly available for earthquakes/disasters
- Multi-frequency systems, to get at new signals
- Airborne, UAVSAR, ground-based platforms.
- Requires contribution from NSF for development of down-the-chain products and research-ready tools
- Better separation of deformation and atmospheric signals (and recording of atmospheric correction metadata)

GNSS/InSAR/LIDAR/etc: New technologies

Frontier: LIDAR

- New platforms for measurements
- Terrestrial: Better moving vehicle positioning and horizontal accuracy via absolute differencing
- Full waveform analysis of data
- Industry participation/Development: Systems that have multiple uses
- Differencing algorithm development needed
- National, International to Global coverage, accelerate current plans.
- Referencing in ITRF
- Improved organization, archiving, and discovery via something like Open-Topography, national research consortium/facility, expand GeoEarthScope
- Mobile Laser Scanning: Very high resolution automobile-mounted systems for e.g., rapid response.

GNSS/InSAR/LIDAR/etc: New technologies

Frontier: Other

- Photogrammetric methods:
  - Structure From Motion, inexpensive, good for short wavelengths.
  - Need ground control points to prevent distortion
- Gravity:
  - Want portable & high-precision; permanent or portable survey mode.
  - Take better advantage of existing data e.g., airborne data being collected over entire US by NGS, and terrestrial data.
- Subsurface methods:
  - Borehole optical fiber instrumentation: e.g. Extensometer and long-baseline strainmeters, deeper monument anchoring.
  - Borehole strainmeters: Instruments are no longer made in US; must build capacity for manufacturing

GNSS/InSAR/LIDAR/etc: New technologies

Broader Impacts

- What new fields might open up with better technology?
- How to get industry involved or what industry systems could be useful to us?
- Training coordinated by facilities to cope with data, processing, broaden use.
- Public awareness and broad use of datasets and their ultimate scientific and societal value.
- Useful single point of access for everything that does not exclude automated access. Options for point and click and NOT point and click, with documentation. Make it easy.
- Reuse of topography data with industry.
- Versioning information on data, metadata and products.

Cyberinfrastructure: HPC, Big Data

Big Data and Big Data Rates: scalability of networks and networking is a big concern.

- Virtualization
- Reproducibility: provide prototype workflows→ make smarter users
- Need "ladders" up the pyramid of desktop to meso to supercomputer scale
- Greater role needed for computational scientists.
- Example: 5,000 stations in Long Beach, how to process with
- "conventional" software, and how to store data and intermediate results?

Standards & Longevity:

- Need for new data formats--collaborate with industry?
- Web-services across multiple domains
- EarthCube, IRIS, UNAVCO: need domain scientists' involvement, should adopt common standards. How much of EarthCube can be used for the Facility of the Future?
- Promote se of DOIs that can be referenced.
- How to cite software? One model is Zenodo, but doesn't meet needs of all. CIG is studying.

Cyberinfrastructure: HPC, Big Data

Integration of DIverse Datasets

- seismic, GPS, MT, integrate horizontally, and then build on that vertically --- Facility of the Future should enable this.
- E.g. all the EarthScope assets on the same map
- including mobile platforms (e.g. drones, floats, …) presents challenges

Cyberinfrastructure: HPC, Big Data

Scientific Computing: Need to support multiple models, some new

- cybercapability on site, local control
- cloud computing
- Use HPC centers:
- → not only lots of "cycles" but also lots of "data",
- → How do we demonstrate scalability before we get to the HPC machines?
- → Rethink the HPC allocation model - easy to get for "production" runs, hard to use it the way our science works
- A new model - computing in residence? E.g. travel to use a CAVE. Use more broadly?
- HR challenge keep "support" people in house-- need flexibility and reliability.
- → consider partnerships with DOE, Exceed. How about Google or Amazon? What about intellectual property issues?
- → Facility of the future with many more people to help with code optimization etc,
- Need to have serious discussion with NSF about funding data management plans. Currently, some work soaked up by CIG, but not proportional increase in money. Researcher on the ground also needs extra money to pay grad student, etc. to work with the facility to document, archive, test, etc. effectively

Cyberinfrastructure: HPC, Big Data

Teaching and the Next Generation

Should requirements in our geophysics/geology programs include programming/computational science?

- Conversely, can we entice computer science majors to intern with us so we grab some of them early?
- Role of byte-size projects that beginning students CAN do. Either pieces of the whole, or simplified versions of the whole.
- The facility of the future might take the lead in producing actual content for an "online textbooks" on the "practice" of geodesy, seismology, and other techniques. These could include exercises in obtaining and processing facility data with best practices. A bit like the New Manual of Observatory Practice.

Seafloor Sensors

- **Key questions:**
- These have been addressed multiple times in previous groups.
- 18 white papers mentioned oceans.
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- Amphibious science will be important.
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Seafloor Sensors

Foundational:

- **Having pool of OBS, EM/MT and geodetic is essential. Current pool needs maintaining and updating.**

- OBSIP – 180 BB, 20 with shallow water/trawl shield
- 4 component with APG/DPG 1yr, 100-5300m (some OBSs will go deeper)
- 94 SP
- Improvements needed- longer deployments (2yr), deeper, More instruments?

- Currently, MT instruments are not part of NSF facility. Need to explore options with this.
- We currently have seafloor MT wideband/CSEM instruments (SIO- 160, 1 month deployment), and long-period MT insturments (WHOI (20 LP MT, 1 yr deployment)

- Geodetic instruments are also not part of a facility. Expand existing geodetic instruments. Best value is GPSA, expand from 12 (4 sites) to 51/3=17 sites?
- Transponders now commercially available. second component-waveglider.
- Good to have other approaches besides GPSA

- Maintain active seismic capability R/V Langseth- source and MCS.
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- Maintain and support Controlled Source EM capability

Seafloor Sensors

Frontier

- **Fleet of community instruments**, larger pool, more support of engineers and data support. Maintain a percentage of funds for development to encourage PIs to next generation instrument development.
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- Improved shallow water operations for OBS.
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- Smaller, faster OBSs
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- Self calibrating pressure gauges for absolute pressure.
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- Expand options for other Geodetic methods:Direct path acoustics; Acoustic extensionometers; Optical fiber strainmeter.
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- Improved real time data access with multiple data sets. Some technology exists to do this with wave gliders. Would enable GSN type deployments in remote locations.

Problems to be solved:

- Improved Power Supplies
- New sea water lithium?
- Pinkel- seafloor turbine?
- Clocks

Blue Sky Thinking About Broader Impacts in a Changing World: New technology, New students and New research

Bridge between our research community and other communities, such as hazards, climate, geotechnical, energy/resources, infrastructure planners.

Foundational:

- E&O Staff (including public affairs and media)
- Supporting products (e.g. end-user products)
- Workshops, summer courses
- Teachable moments for use in education, press and public outreach

Frontier:

- Cross-disciplinary workshops and other professional development
- Cross-disciplinary teaching and research opportunities at all levels
- Resources for public planners to anticipate the intersection of science and societal impacts.
- Build bridges for trans-disciplinary work (integrate science community with business/policy/industry partners).

Blue Sky Thinking About Broader Impacts in a Changing World: New technology, New students and New research

- *Engage citizens and students*
- *Foster cross-disciplinary communities (geo-bio, geo-policy, etc.)*
- *Increase diversity through cultural competence*

Foundational:

- Staff to facilitate networks and learning opportunities
- Supporting products (e.g. usable data and metadata)
- Existing programming in E&O (REUs, RESESS, etc.)

Frontier:

- Develop materials for ubiquitous learning (online modules, TED-type talks, interactive visualizations, MOOCs)
- Build instructional material based on education research
- Build capacity using new technologies for crowd-sourcing data collection, oversight and analysis