Inverse methods in the era of machine learning and deep learning (Part 2)

Prof. Sang-Mook Lee

Seoul National University

smlee@snu.ac.kr

The Abdus Salam International Centre for Theoretical Physics

International Union of Geodesy and Geophysics (IUGG)

SNUMGGL

Seoul National University Marine Geophysics & Geodynamics Lab

A Bit of History

- RV Onnuri (1450 ton, 68 m long, built in Norway KIOST 1992)
- RV Tamhae 2 (2500 ton, seismic vessel, built in Norway KIGAM 1995)
- RV Araon (7000 ton, icebreaking research vessel, KOPRI 2007)

at Johns Hopkins University in Baltimore, Maryland. The data have yielded new ways to classify tumours and pointed to previously unrecognized drug targets and carcinogens. But some researchers think that sequencing still has a lot to offer. In January, a statistical analysis of the mutation data for 21 cancers showed that sequencing still has the potential to find clinically useful mutations (M. S. Lawrence *et al. Nature* **505**, 495–501; 2014).

On 2 December, Staudt announced that once TCGA is completed, the NCI will continue to intensively sequence tumours in three cancers: ovarian, colorectal and lung adenocarcinoma. It then plans to evaluate the fruits of this extra effort before deciding whether to add back more cancers.

EXPANDED SCOPE

But this time around, the studies will be able to incorporate detailed clinical information about the patient's health, treatment history and response to therapies. Because researchers can now use paraffin-embedded samples, they can tap into data from past clinical trials, and study how mutations affect a patient's prognosis and response to treatment. Staudt says that the NCI will be announcing a call for proposals to sequence samples taken during clinical trials using the methods and analysis pipelines established by the TCGA.

The rest of the International Cancer Gene Consortium, slated to release early plans for a second wave of projects in February, will probably take a similar tack, says co-founder Tom Hudson, president of the Ontario Institute for Cancer Research in Toronto, Canada. A focus on finding sequences that make a tumour responsive to therapy has already been embraced by government funders in several countries eager to rein in health-care costs, he says. "Cancer therapies are very expensive. It's a priority for us to address which patients would respond to an expensive drug."

The NCI is also backing the creation of a repository for data not only from its own projects, but also from international efforts. This is intended to bring data access and analysis tools to a wider swathe of researchers, says Staudt. At present, the cancer genomics data constitute about 20 petabytes (10^{15} bytes), and are so large and unwieldy that only institutions with significant computing power can access them. Even then, it can take four months just to download them.

Stimulus funding cannot be counted on to fuel these plans, acknowledges Staudt. But cheaper sequencing and the ability to use biobanked biopsies should bring down the cost, he says. "Genomics is at the centre of much of what we do in cancer research," he says. "Now we can ask questions in a more directed way." ■

SEONYONG LEE/KYT/REDUX/EYEVINE

Marine biologist Sang-Mook Lee has pushed for academic involvement in South Korea's research ships.

OCEANOGRAPHY

Korea opens up its ocean science

Ships used mainly for seabed surveys will expand in focus.

BY MARK ZASTROW

South Korea's ocean-going research programme is changing tack. For more than two decades, it has focused on discovery and exploitation of minerals on the sea floor, but now a move is afoot to expand the research agenda. A 5,900-tonne ship — the *Isabu* — is being built with the capability to launch autonomous underwater vehicles, perform sea-floor-penetrating seismic surveys and collect sediment cores up to 40 metres long.

The current flagship, the 1,422-tonne *Onnuri*, spends about three-fifths of its time scouring the sea floor for mineral deposits under the direction of the deep-sea minerals group at the Korean Institute of Ocean Science and Technology (KIOST) in Ansan. That heavy economic emphasis is set by the Ministry of Oceans and Fisheries, which oversees KIOST as well as the nation's ports and shipping.

The ministry's hold is so complete that in 22 years of operation, no academic researcher outside KIOST has ever led a cruise. "This is really scandalous," says marine geophysicist Sang-Mook Lee of Seoul National University. Although scientists at his university and elsewhere have been able to work aboard the ship, they have been frustrated by a near-complete lack of say in where the *Onnuri* goes or what research questions it pursues.

In March, that is set to change: KIOST will start to make *Onnuri*'s upcoming cruise tracks public, and will invite outside researchers to propose projects that can be done along the way, says Gi-Hoon Hong, who became the institute's president in August and has supported broadening the constituency for its research vessels. Eventually, time on the ships, which currently costs up to US$12,000 per day, will be awarded through a merit-based system.

South Korea's focus on mineral exploration dates back to the founding of KIOST in the early 1970s, when the nation was in the middle of a decades-long economic boom. At the time, polymetallic nodules — balls of manganese and other metals such as iron, nickel and cobalt that accumulate on the sea floor — seemed a valuable potential resource. Although international interest in the minerals waned over subsequent decades, the South Korean government continued to fund research on the nodules and other sea-floor mineral deposits.

Securing marine mineral resources is "considered very important to the Korean people, because of the scarcity of land-based natural resources," says Jai-Woon Moon, the head of KIOST's deep-sea mineral research group. And rising prices for metals have renewed the world's interest: Nautilus Minerals of ▶

동서남북

그릇된 經濟 논리 꺾은 '한국의 스티븐 호킹'

이영완 B
산업부 차장
E-mail : ywae@chosun.com
중학생도 이해할 만큼 쉽게 과학기사를 쓰라고 요구하는 데스크들이... 더보기

입력 : 2015.01.12 03:05

이영완 산업2부 과학팀장

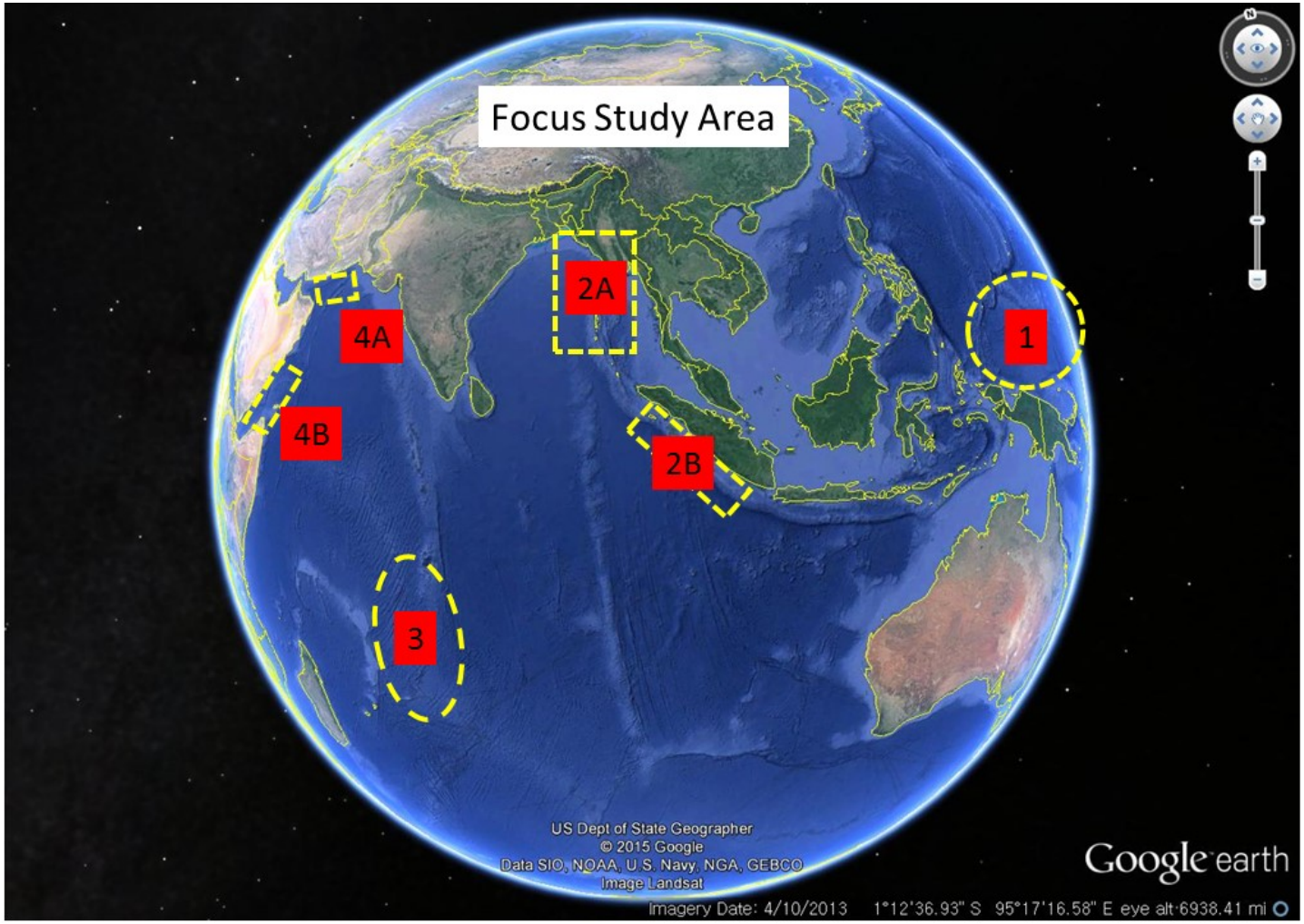
지난 8일 국제학술지 '네이처'에 "한국에서 올 3월부터 대학 연구자들도 해양과학조사선을 활용할 수 있게 됐다"는 기사가 실렸다. 국내 과학계에서 박사급 연구자의 80% 이상이 대학에 있다. 왜 그동안 대학 연구자들은 조사선을 활용하지 못하고 소외됐던 것일까.

1992년 취역한 1422t급 해양과학조사선 '온누리'호(號)는 해양수산부 산하 한국해양과학기술원이 운영한다. 미국·영국·일본 등 해양과학 선진국에서는 국가기관과 대학 등 민간 연구자들이 공동으로 해양과학조사선을 활용하고 있다. 하지만 우리나라는 지난 23년간 민간 연구자가 온누리호 탐사를 지휘한 적은 한 번도 없다.

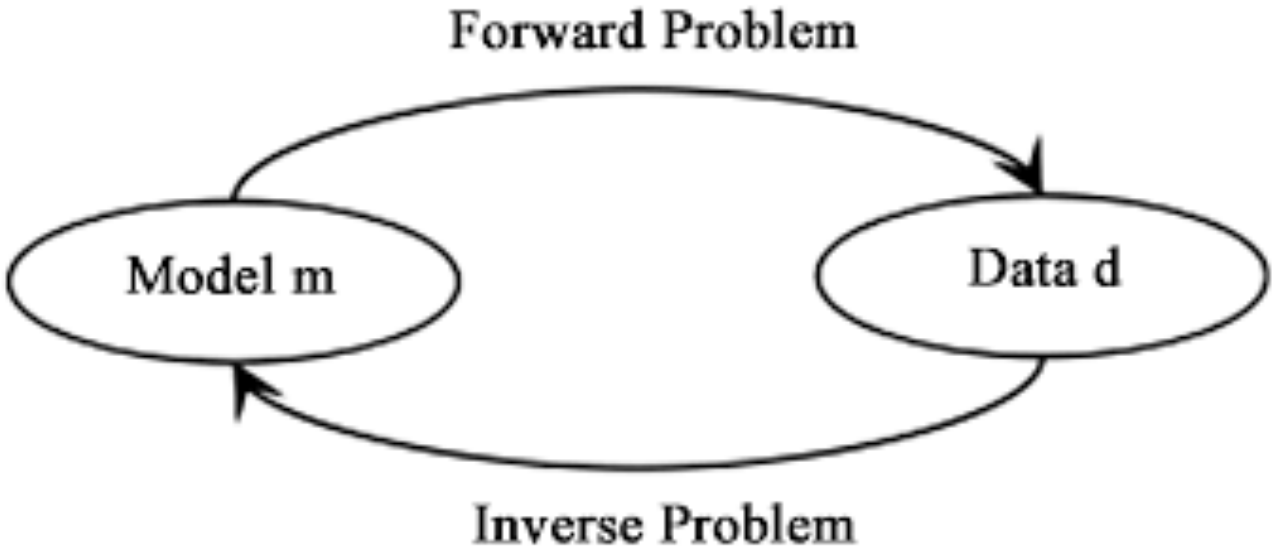
문제는 정부의 그릇된 경제 논리였다. 온누리호는 운항 시간의 5분의 3을 해양과기원의 심해저(深海底) 광물 탐사에 썼다. 대학에서 온누리호를 쓰려고 해도 하루에 수천만원씩 사용료를 내야 해서 엄두를 내지 못했다. 반면 해양과기원은 해수부로부터 해저 광물 탐사 명목으로 1년에 몇십억원씩 해양조사선 사용료를 따로 받았다.

그러나 네이처지는 "해저 광물 채굴에 대해서는 회의론이 널리 퍼져 있다"고 전했다. 해수부 관계자도 "현재로선 해저 광물을 채굴하는 것이 육상 광물 채굴보다 경제성이 낮은 게 사실"이라고 인정했다. 이상묵 서울대 지구환경과학부 교수는 "정부가 계속 해저 광물의 경제적 가치를 말하면 국민에게 거짓말하는 것"이라고 했다.

그런데도 정부는 또다시 예전 방식을 고집했다. 그러자 이상묵 교수는 작년 해수부 국정감사에 증인으로 나와 "새로 건조하는 5900t급 대형 해양과학조사선 '이사부'호의 소유권이 당초 계획과 달리 다시 해양과기원에 돌아갔다"고 폭로했다. 2008년 한국개발연구원(KDI)은 이사부호에 대한 예비타당성 평가에서 "사업성이 떨어진다"며 탈락시켰고, 2차 평가에서는 '대학과 선박을 공유해야 한다'는 조건을 달아 승인했다. 해수부가 이를 어긴 것이다. 이 교수의 폭로가 나온 뒤 해수부는 이사부호를 민간도 활용할 수 있게 하겠다고 약속했다.


Focus Study Area
2A
4A
1
4B
2B
3
US Dept of State Geographer
© 2015 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat
Google earth
Imagery Date: 4/10/2013 1°12'36.93" S 95°17'16.58" E eye alt 6938.41 mi

What is the inverse problem (**inversion**)?



$A\,\mathbf{x} = \mathbf{b}$ $A\,\mathbf{x} = \lambda\,\mathbf{x}$

Linear(-ized) inverse problems can be formulated in the following way:

$$d_i = G_{ij} m_j$$

(summation convention applies)

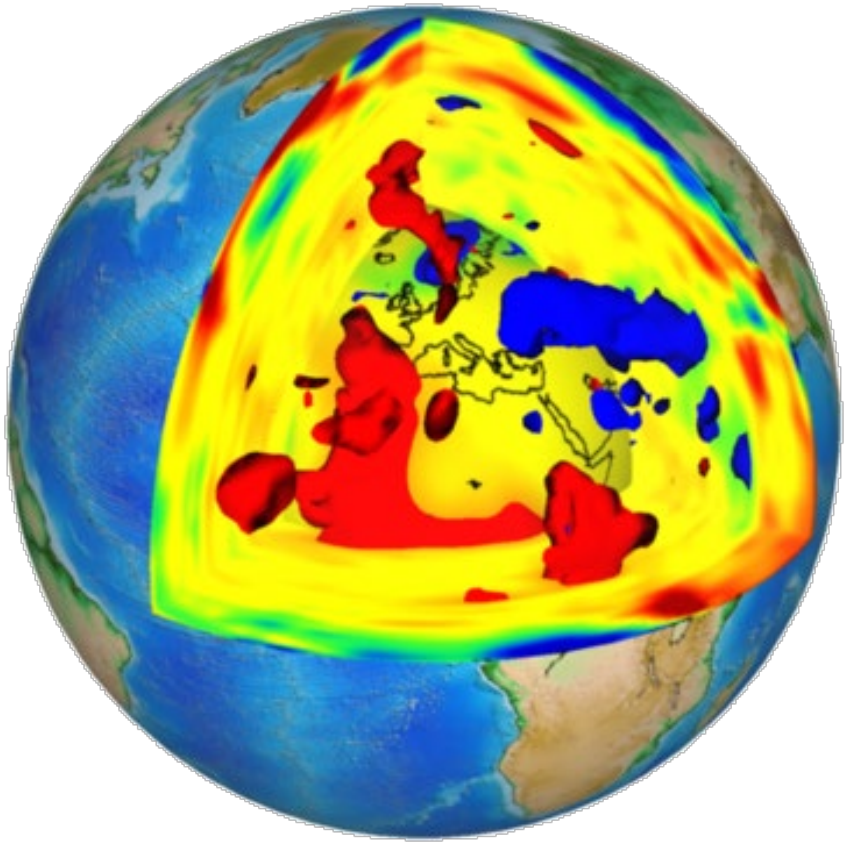
i=1,2,...,N	number of data
j=1,2,...,M	number of model parameters
G_{ij}	known (mxn)

We observe:

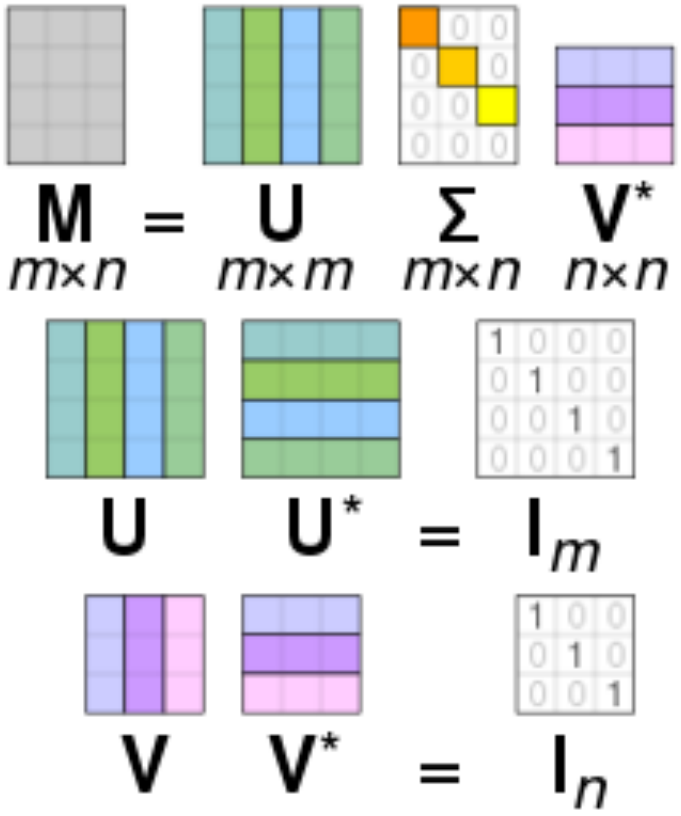
- The inverse problem has a unique solution if N=M and det(G)≠0, i.e. the data are linearly independent
- the problem is overdetermined if N>M
- the problem is underdetermined if M>N

Taught under the name of REGRESSION in ML

Global Seismic Tomography



Singular Value Decomposition



Taught under the name of PCA in ML

Then all of a sudden, *Machine Learning and Deep Learning*

REVIEW

GEOPHYSICS

Machine learning for data-driven discovery in solid Earth geoscience

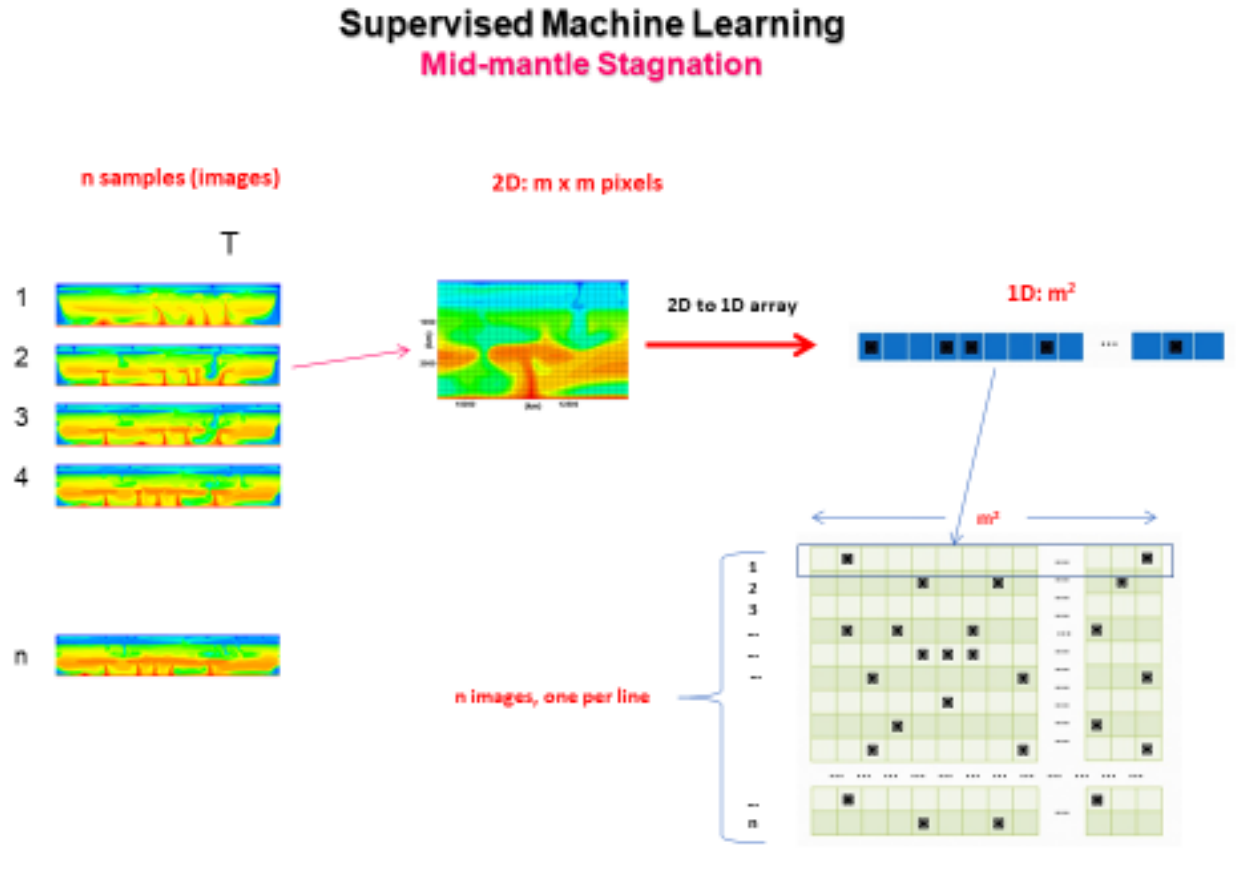
Karianne J. Bergen[1,2], Paul A. Johnson[3], Maarten V. de Hoop[4], Gregory C. Beroza[5]*

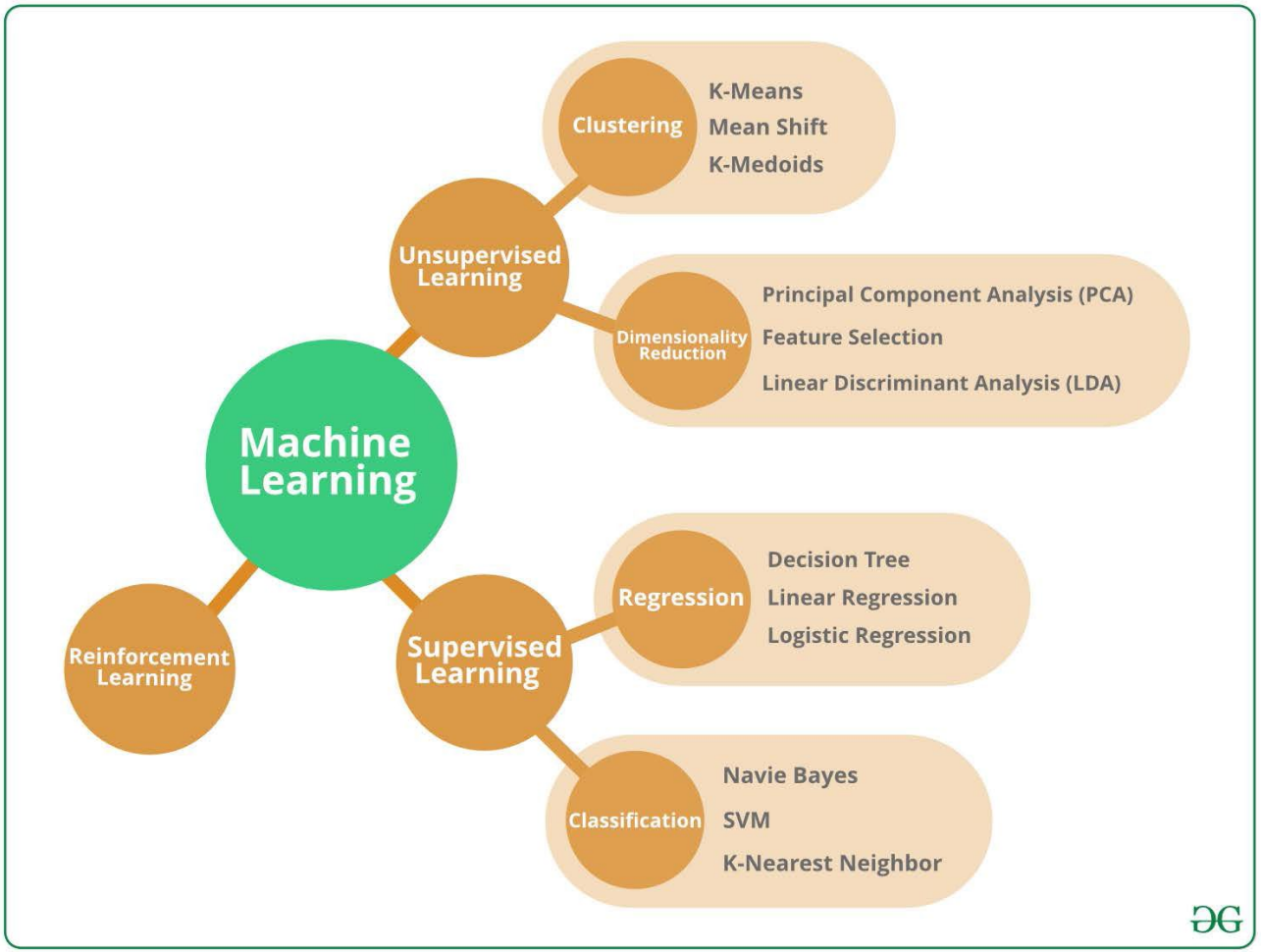
Understanding the behavior of Earth through the diverse fields of the solid Earth geosciences is an increasingly important task. It is made challenging by the complex, interacting, and multiscale processes needed to understand Earth's behavior and by the inaccessibility of nearly all of Earth's subsurface to direct observation. Substantial increases in data availability and in the increasingly realistic character of computer simulations hold promise for accelerating progress, but developing a deeper understanding based on these capabilities is itself challenging. Machine learning will play a key role in this effort. We review the state of the field and make recommendations for how progress might be broadened and accelerated.

Science 2019

An Example of Machine Learning for Geodynamical Problems

(Shahnas & Yuen, Constraints on Geophysical Parameters Using Machine Learning Algorithms, JGR 2018)



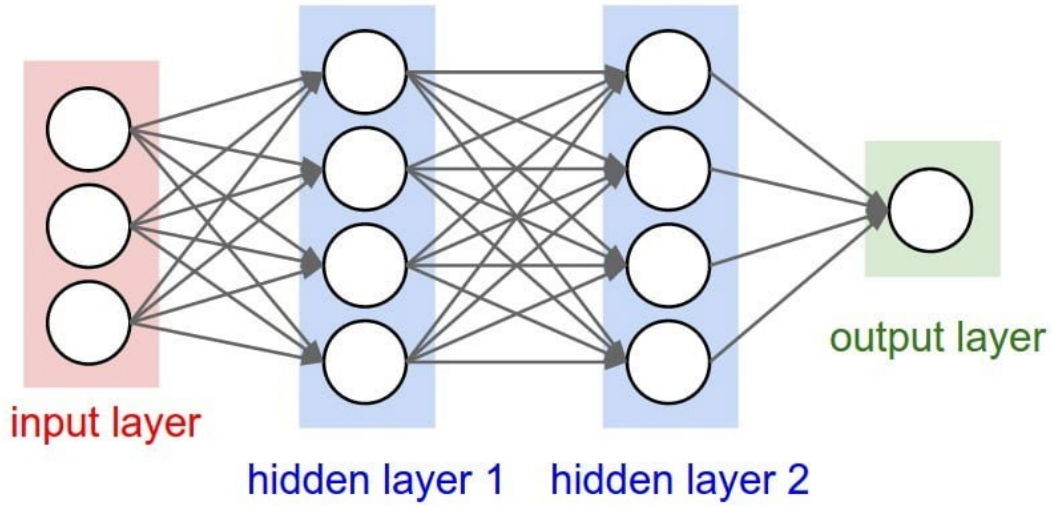


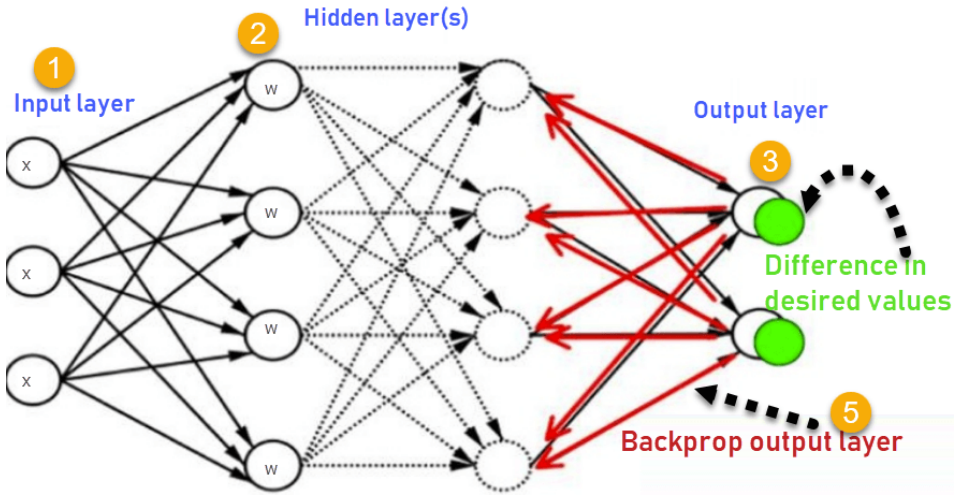
With special emphasis on the principle and applications of

- **Linear Algebra**
- **Probability**
- **Optimization**

as well as becoming familiar with programming tools such as

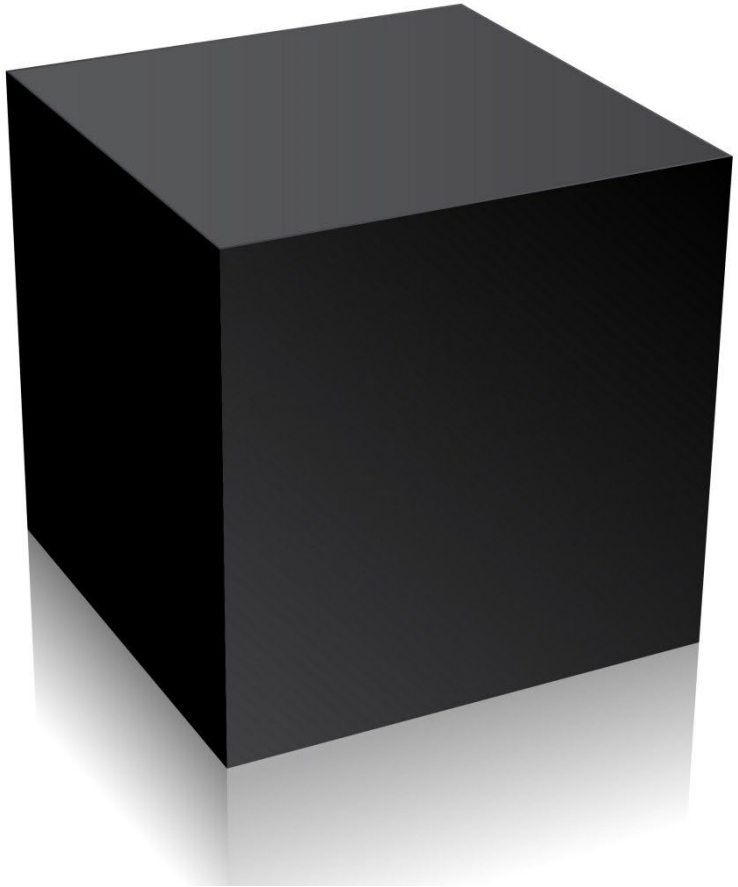
- **Python (numpy, pandas, matplotlib)**
- **C/C++**



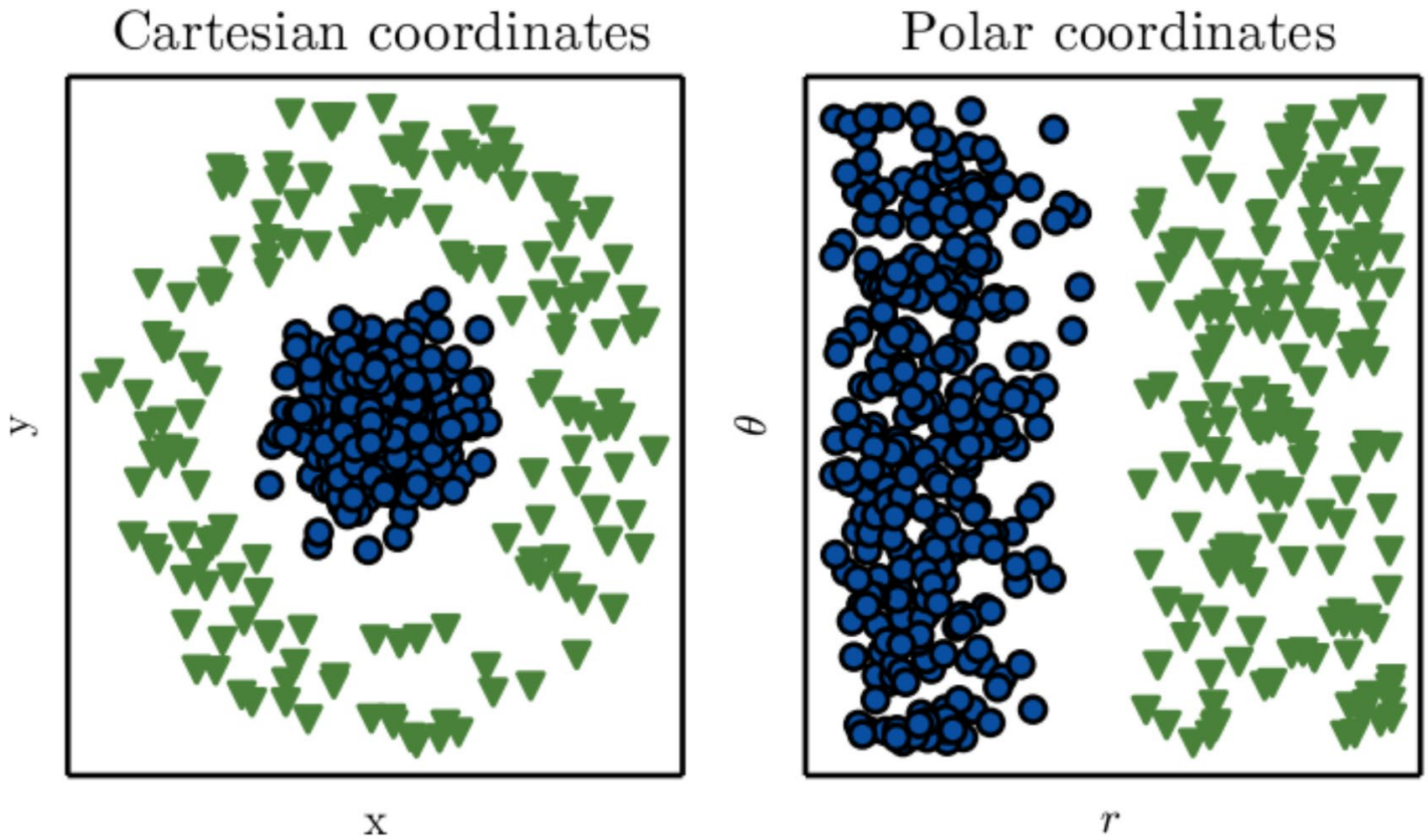


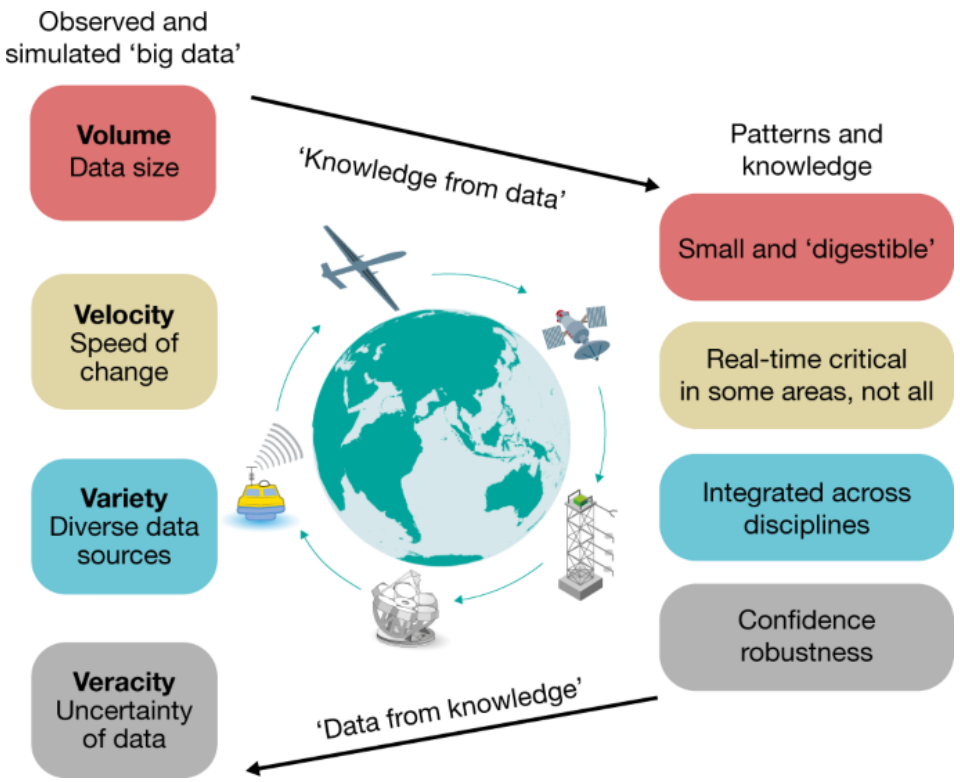
Back propagation

A black box



But do this in complex multidimensional sense





Scientists propose deep learning method for atmospheric aerosol retrieval

by Li Yuan, Chinese Academy of Sciences

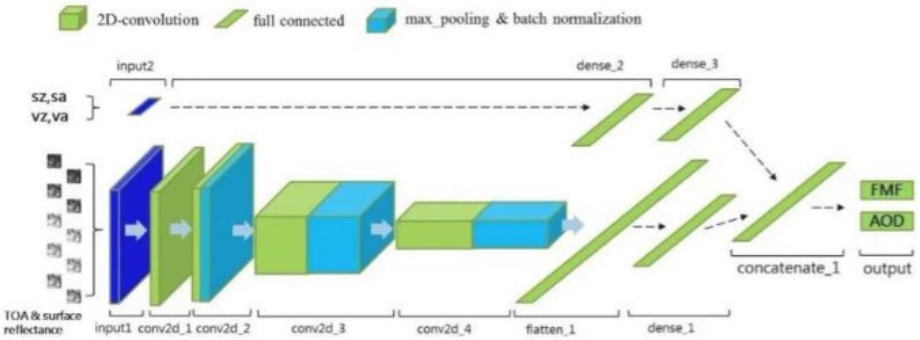
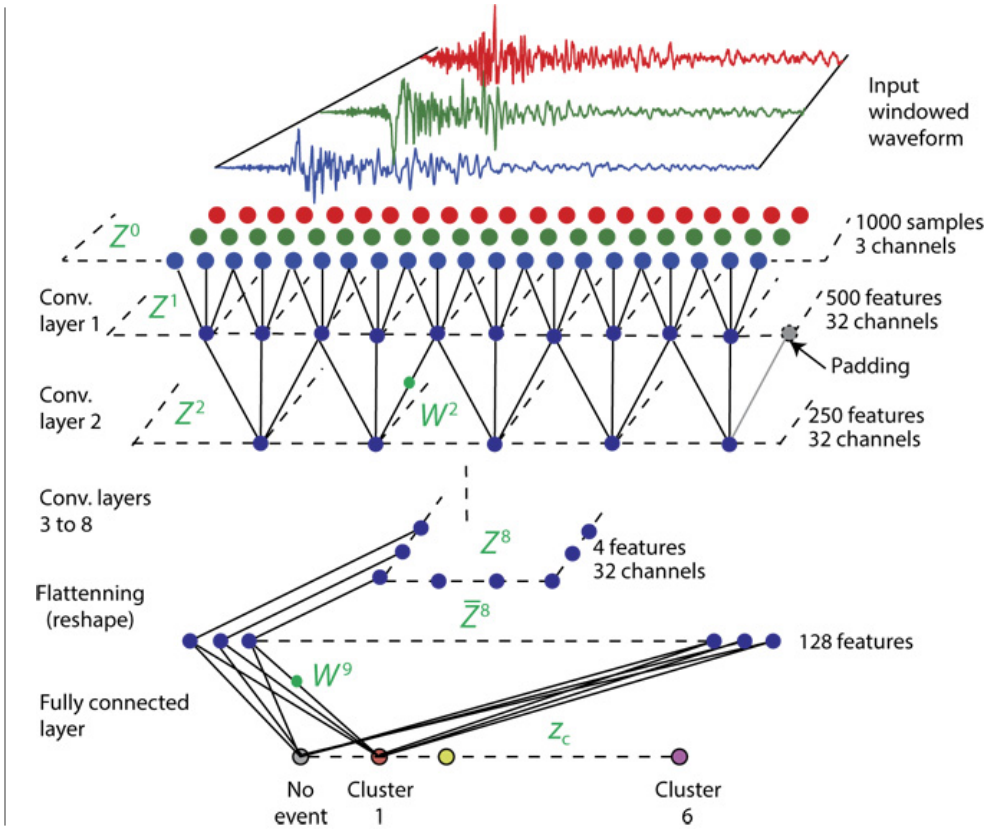


Fig. 1 The multi-input neural network architecture of MODIS FMF and AOD ...

NEURAL INFORMATION PROCESSING SYSTEMS

Single-Station Earthquake Location Using Deep Neural Networks

S. Mostafa Mousavi, Greg Beroza



Limitations of Deep Learning

딥러닝
의
한계

작은 변형에 영상분류 신경망의 인식 실패

출처 : (1) A. Mardy et al. "Brief Introduction to Adversarial Attack," Gradient Science, 2018
(2) T. Brown et al. "Adversarial Patch", arXiv, 2018
(3) K. Eykholt et al. "Robust Physical-World Attacks on Deep Learning Visual Classification", arXiv 2018

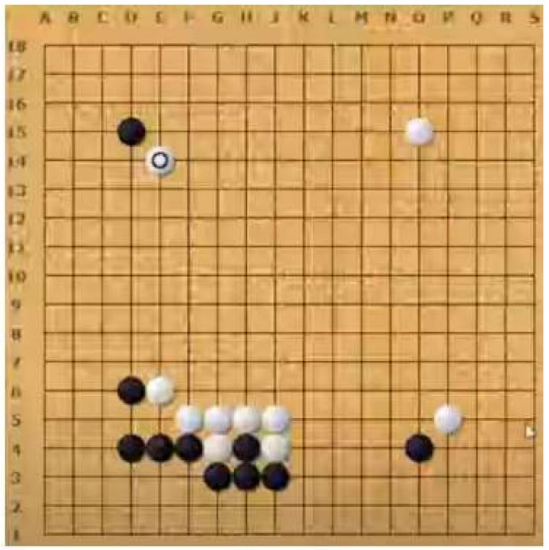
Cannot generalize; a small change in condition results in failure

딥러닝
의
한계

일반화 못하는 딥러닝의 문제점

2% 밝게 했을 때
성능저하

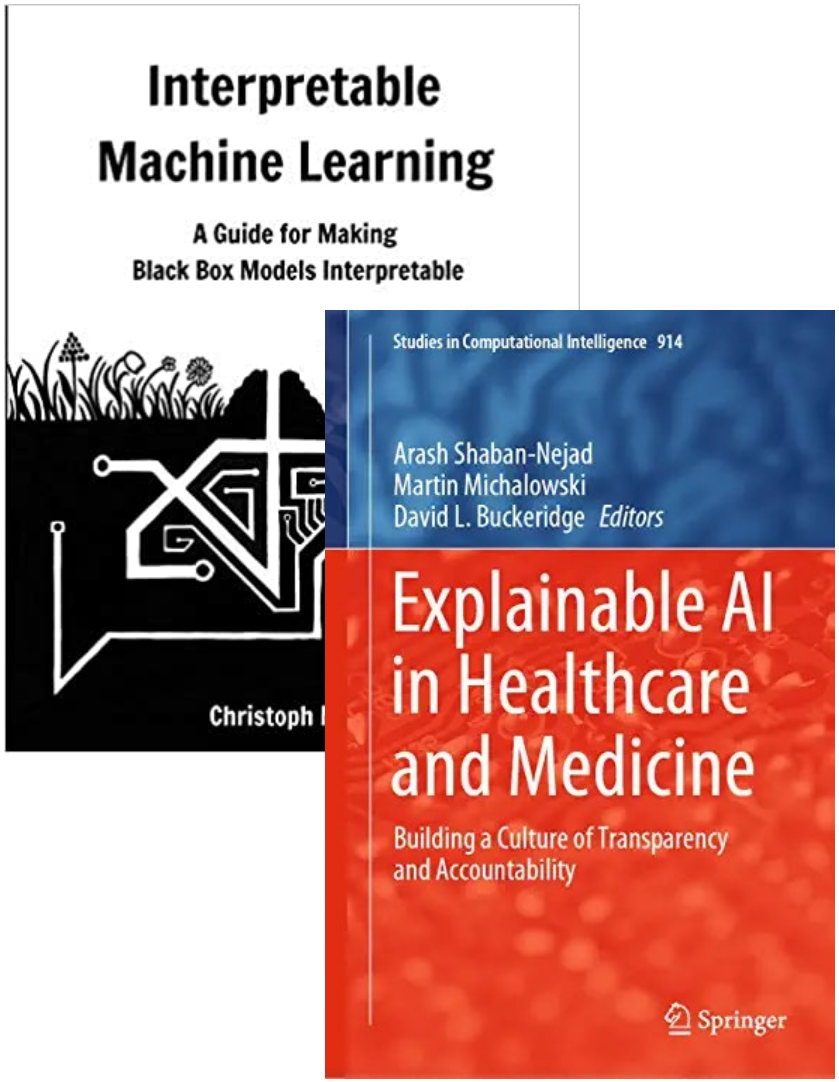
반사판을 조금 올리면
성능저하



18x18 Go - Board Games Ep. 154

18x18 바둑에서 알파고?

뭣을 배웠는가를 모르고, 일반화의 문제로 작은 상황 변화에 취약



I think it all boils down to how do we put a priori information such that the results does not come out crazy

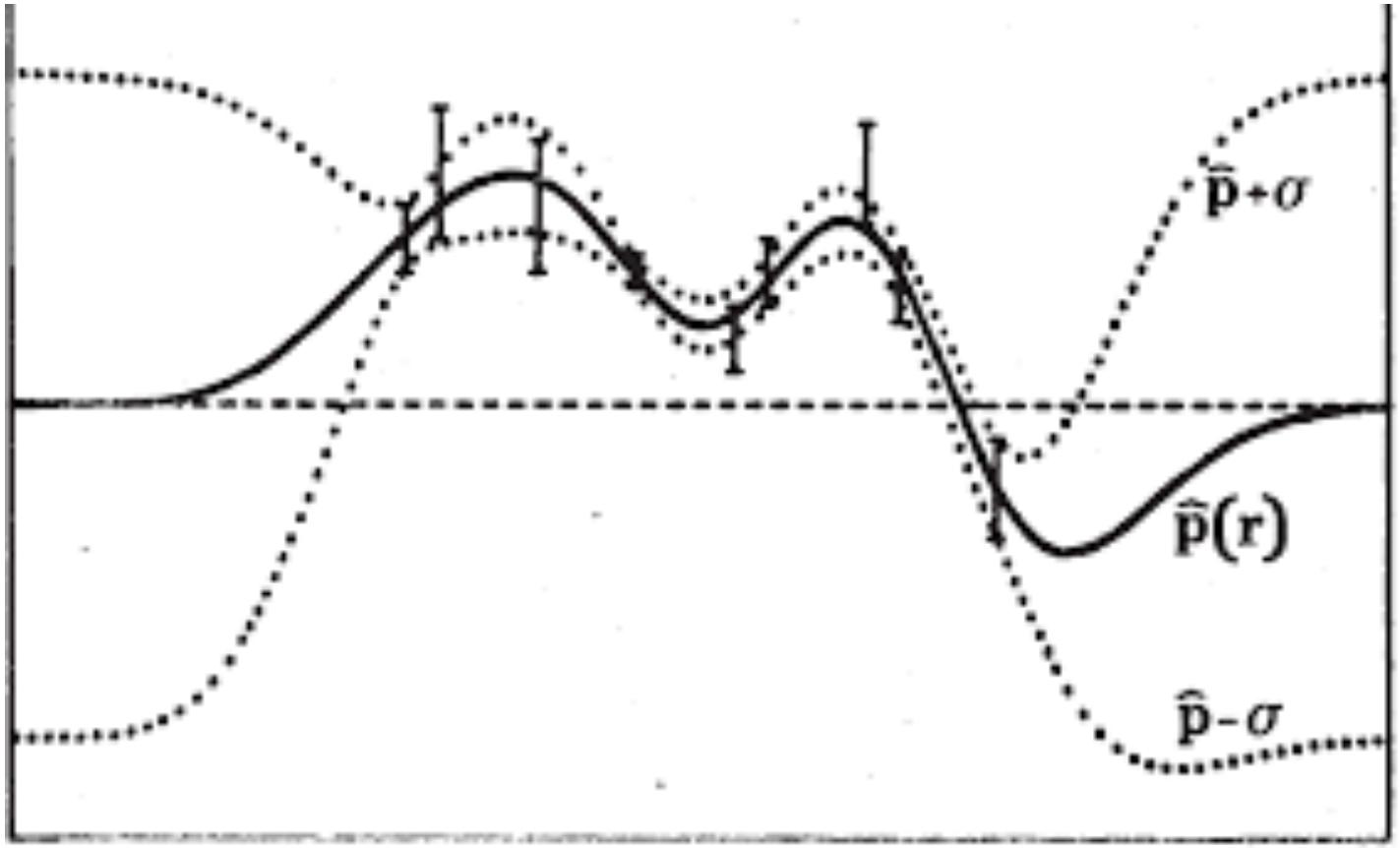
딥러닝
의
한계

자율자동차 왜 안전하지 않은가?

자율주행 모드로 주행하던 테슬라 자동차가 고속도로에 누워있던 트럭과 충돌. 2020.6.2

자료출처 : https://www.taiwannews.com.tw/en/news/3943199

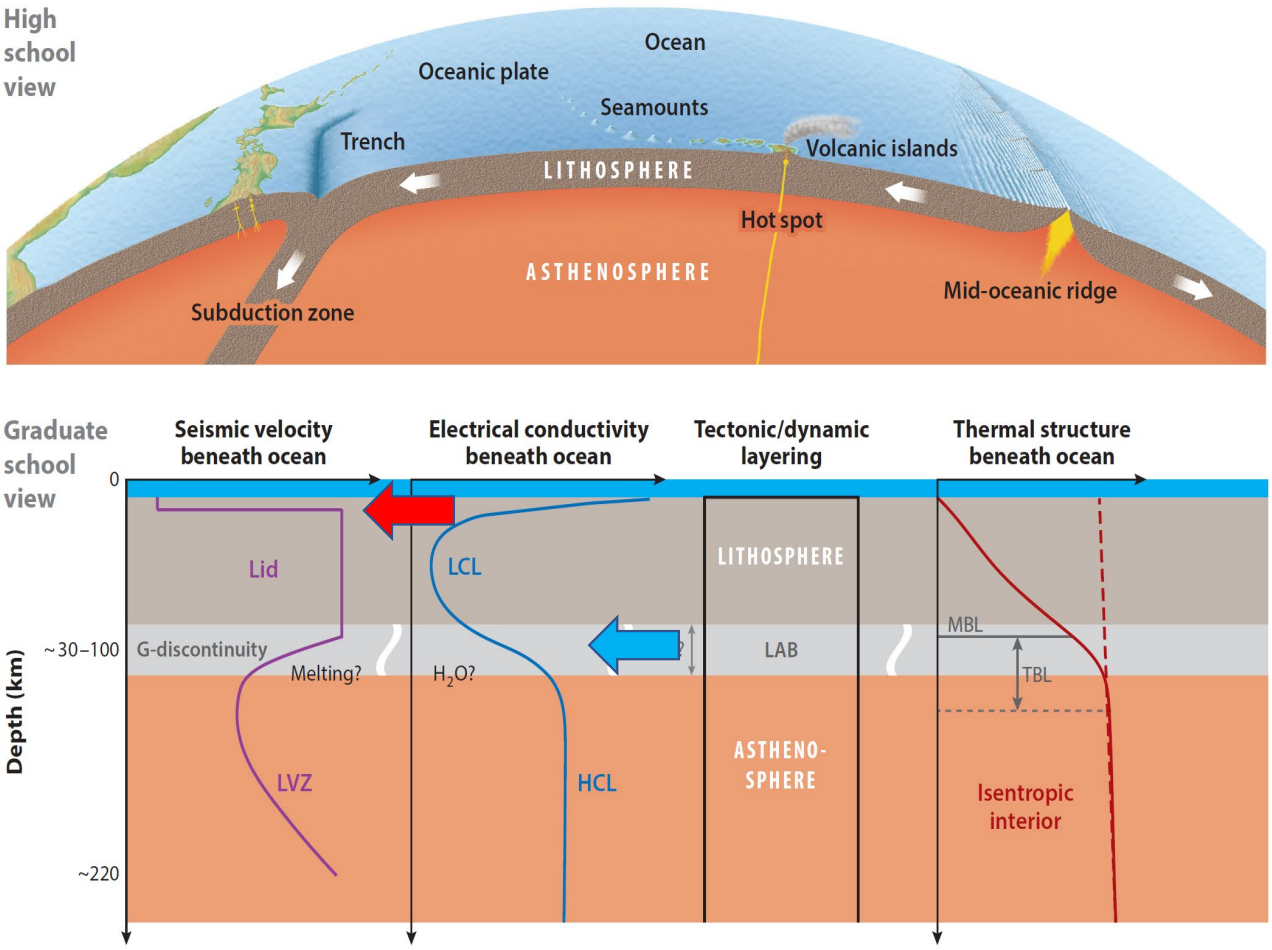
The solid line will be the updated your information and everything has uncertainty.



Most importantly we never have enough data when you are trying to discover new phenomena

Why I am not so interested in Deep Learning for now, except for pedagogical (educational) reasons?

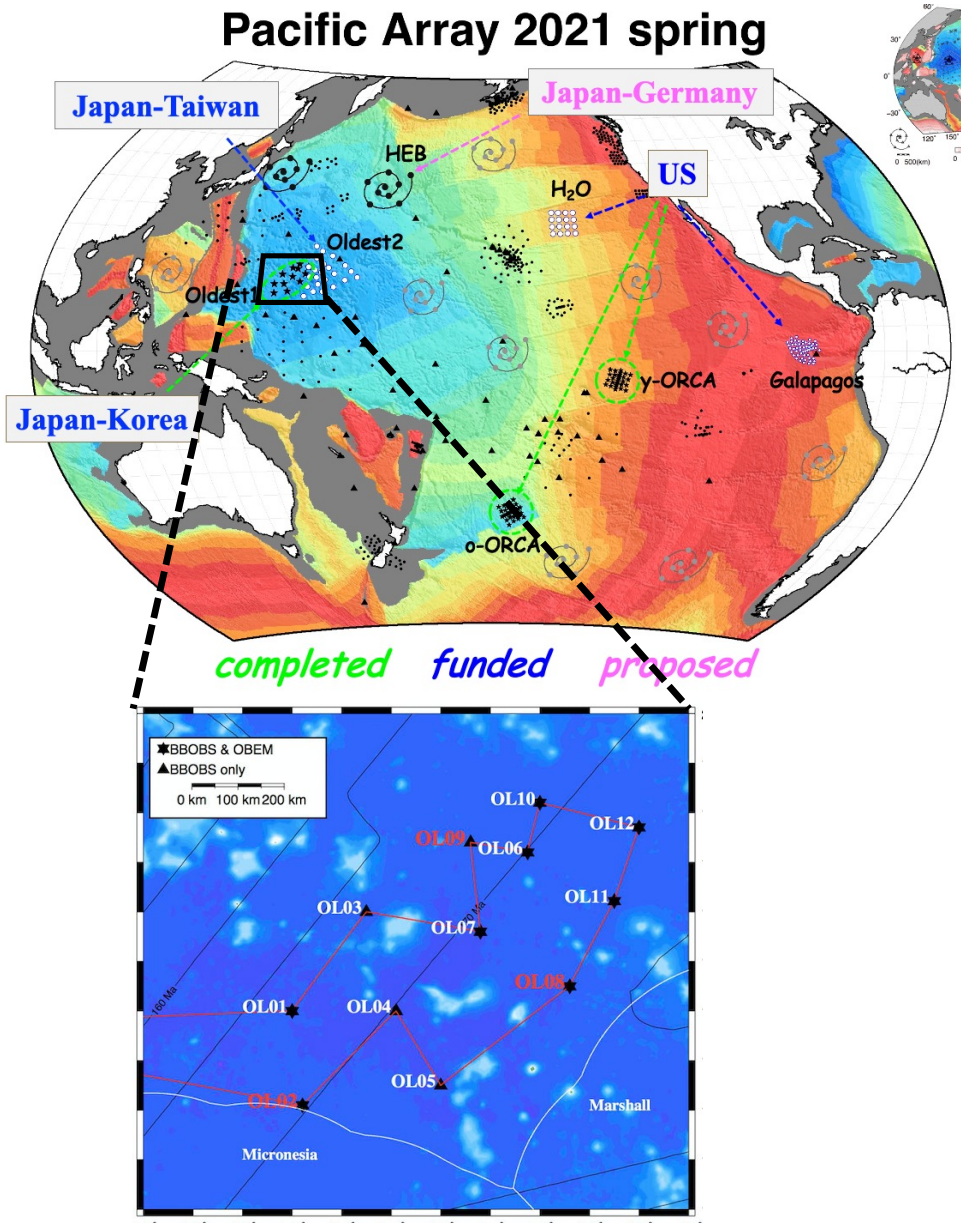
판구조론의 중요한 미스테리

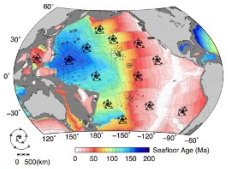


(Kawakatsu & Utada, Annu. Rev. Earth Planet. Sci. 2017)

지각과 맨틀의 경계면(즉 모호면)은 잘 알려졌지만 판의 이동을 결정하는 **LAB**(암석권과 연약권의 경계)는 찾기가 매우 힘들다.

하지만 최근 지진계와 관측기술의 발달은 미세한 LAB를 찾아내기에 이르렀다.



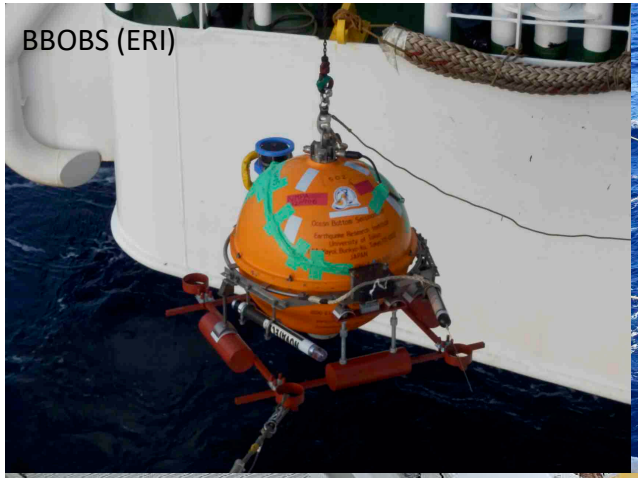


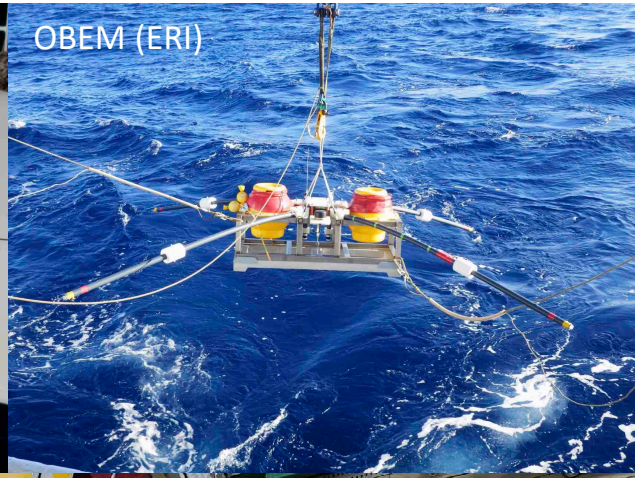
Pacific Array

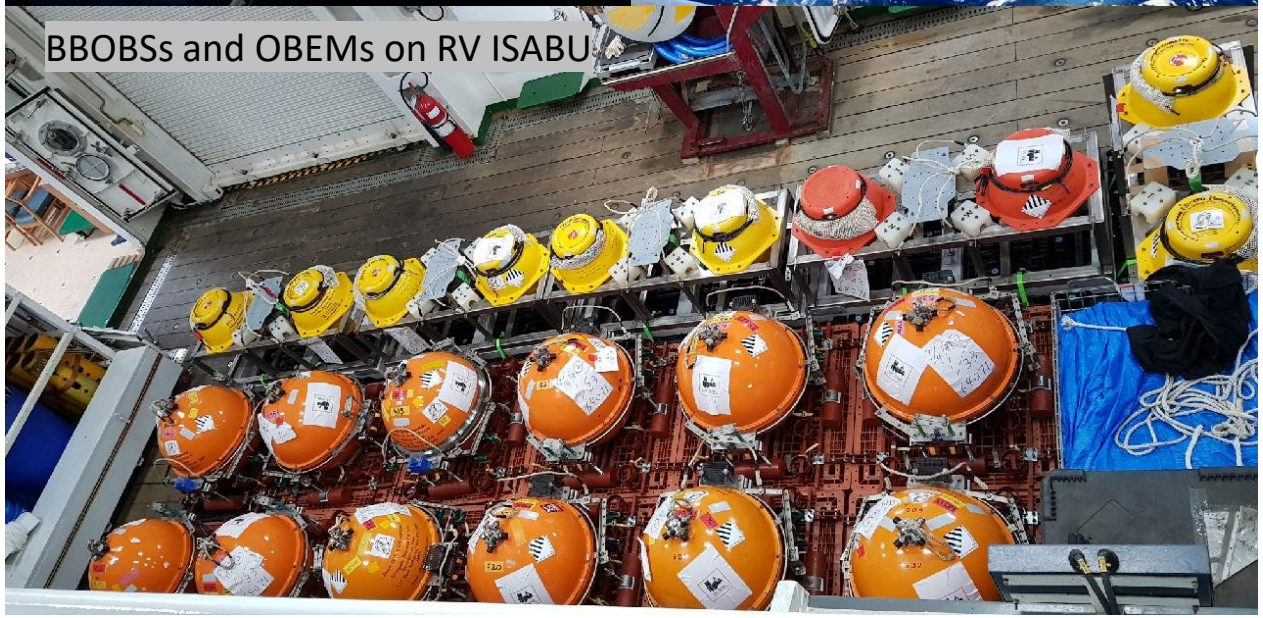
- International collaborative project
  - US, Japan, Korea, Germany, …
- "Array of Arrays"
  - Consisted of multiple array observation projects
  - Each project would solve regional problems independently, and collectively provides information to decipher plate-wise enigma such as the evolution of LAB

Oldest-1, Pacific Array project

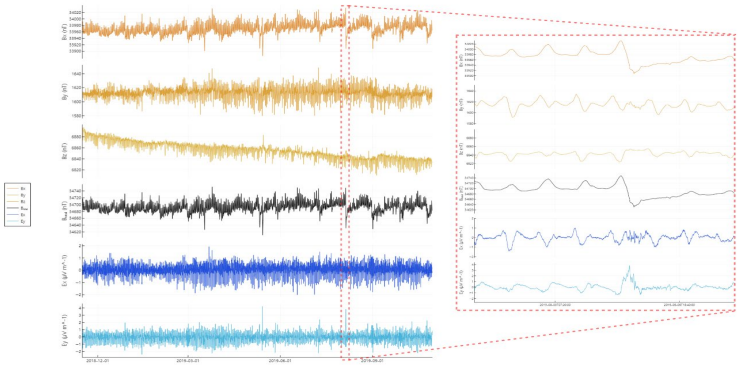
- Korea-Japan international collaboration
- ~175 Ma Pacific plate (the oldest part of Pacific oceanic plate)



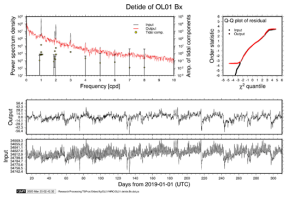




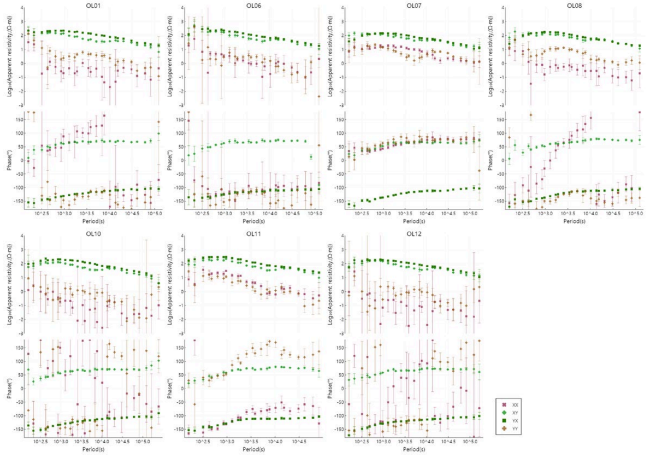
- 12 BBOBS (Broadband Ocean Bottom Seismometer) and 7 OBEM (Ocean Bottom Electro-Magnetometer) were installed and retrieved after ~1 year of deployment (2018-2019)
- Instruments provided by ERI and research vessels of KIOST (RV Isabu, RV Onnuri)
- Excellent example of International collaboration in geophysical data collection



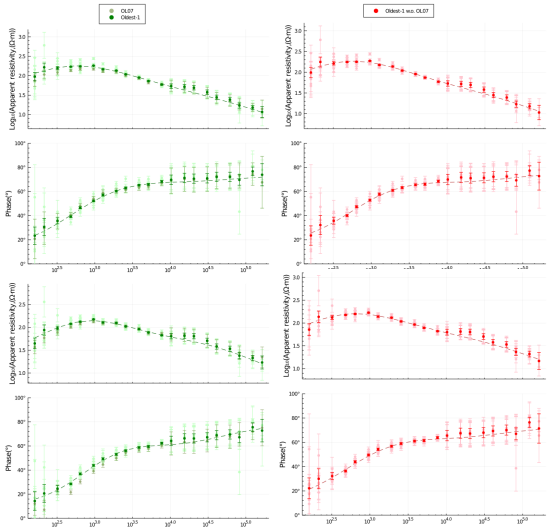
Example raw data from an OBEM



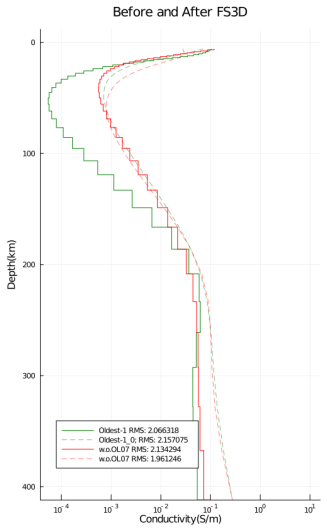
Data processing

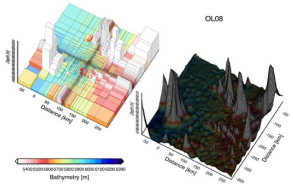


Sounding curves from raw data

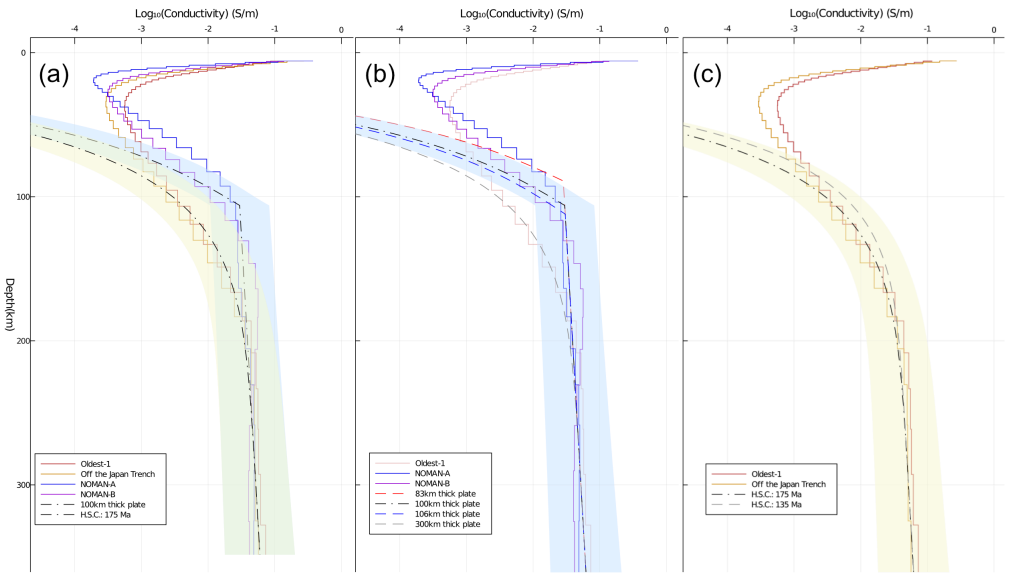


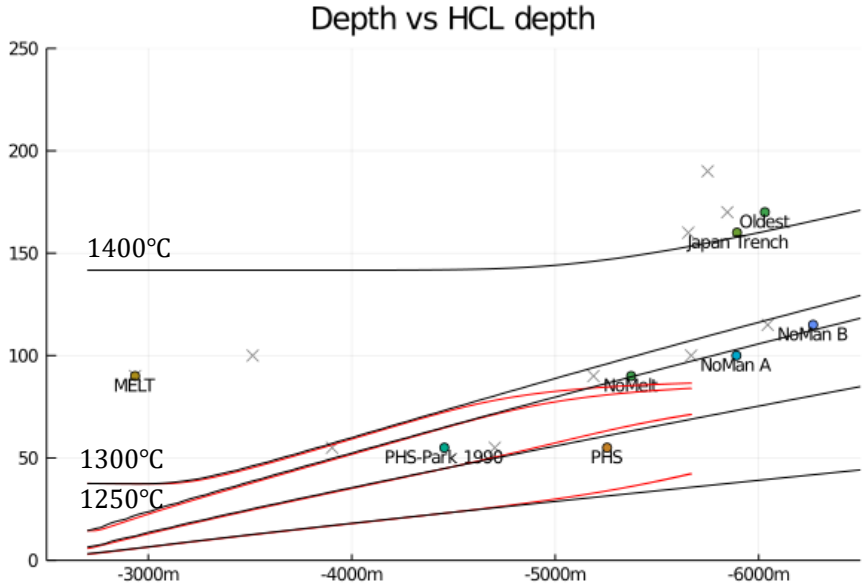
1-D regional resistivity structure



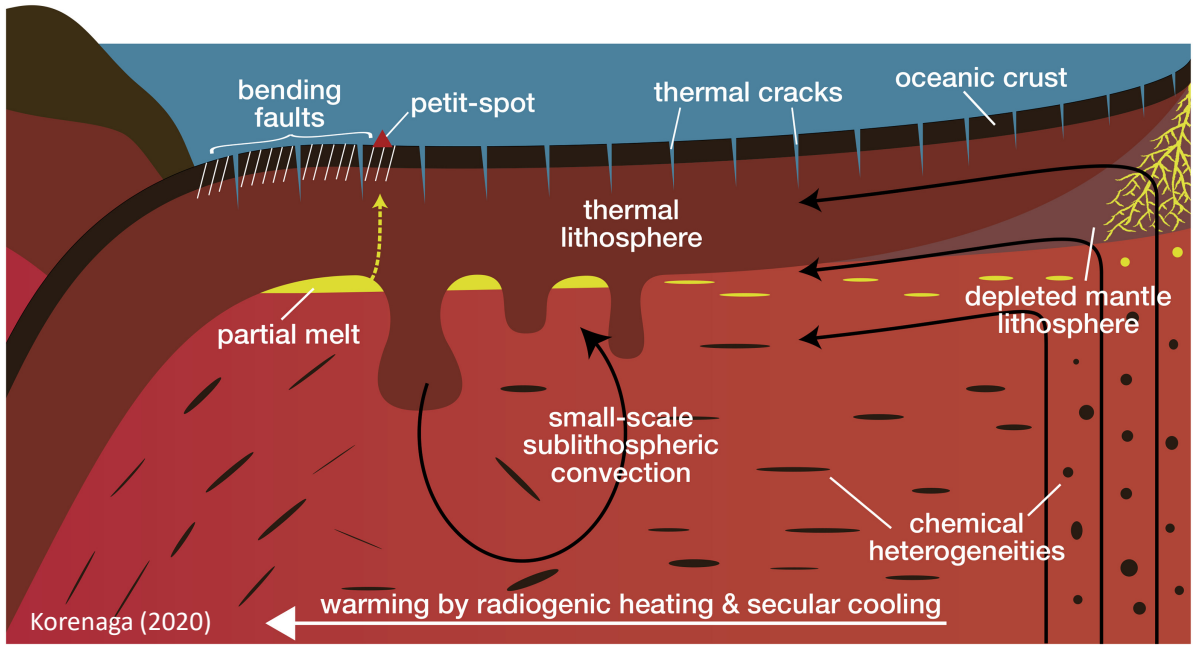


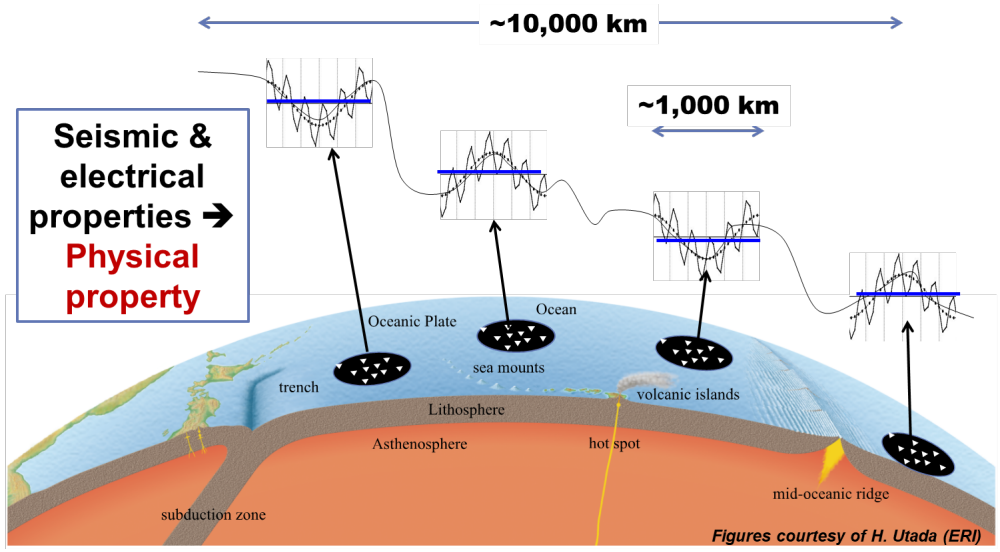
Topographic correction & 1-D inversion





- In comparison with other electrical conductivity profiles of the Pacific plate, Oldest-1 result shows complex nature of LAB's thermal structure.
- Upper panels show comparison with calculated conductivity profiles from plate-cooling and H.S.C. cooling temperature profiles, with 100 w.t. ppm hydrated olivine assumed. (Gardes et al. (2014))
- It showed all profiles below resistive lid could be explained well with the adiabat, but the HCL depth could not be explained with a single thermal model such as half-space cooling, plate -cooling, or other recent models (e.g., Korenaga et al. (2021))
- More ocean-bottom observation is needed to understand LAB and the lithosphere-asthenosphere system (e.g., Oldest-2 project planned for 2022)



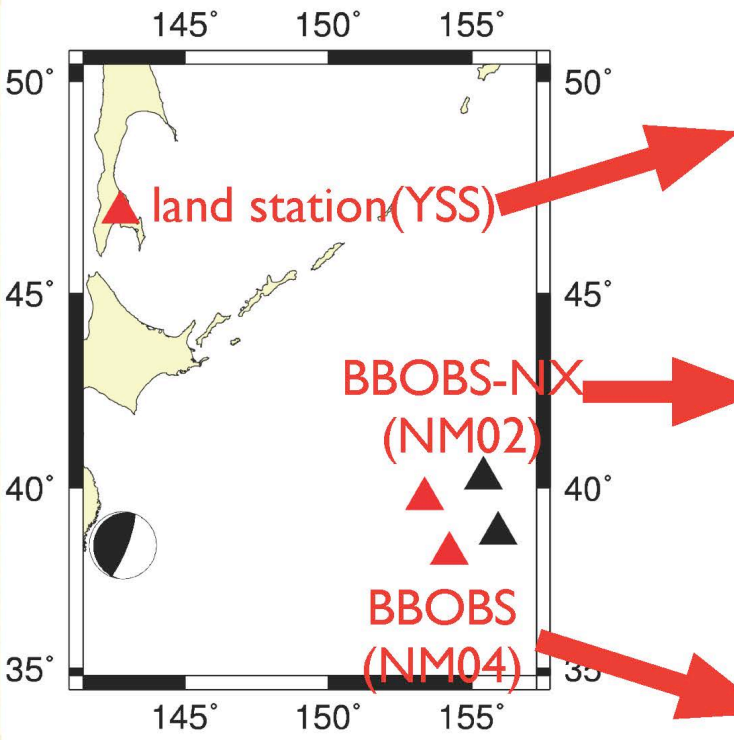


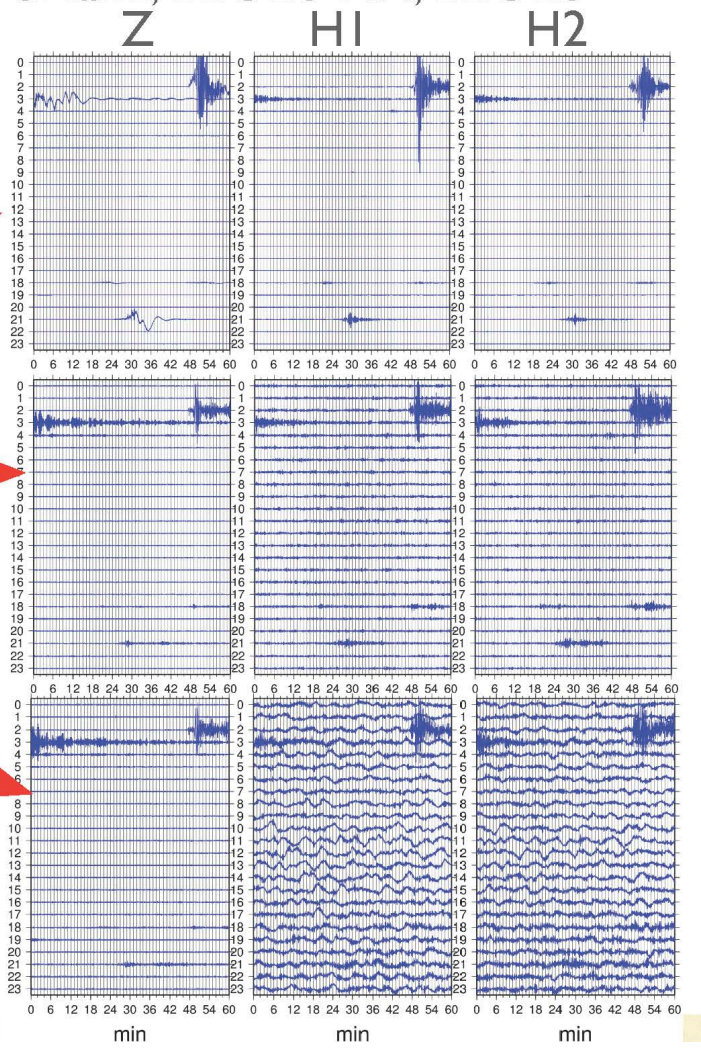
- Lithosphere-Asthenosphere boundary(LAB):
  - The key part of plate tectonics
- LAB and its evolution in mechanical, compositional, thermal aspects remains to be solved
- Oceanic LAB is expected to be simpler and more representative than its continental equivalent
- To understand various properties of LAB, in situ observations are necessary
- Therefore, ocean-bottom geophysical observation has been utilized to understand the oceanic LAB system

Now we have the ship that can go basically everywhere, we need new type of novel instruments that can help us in Earth sciences.

The development of next-generation sensors and instruments for global observations

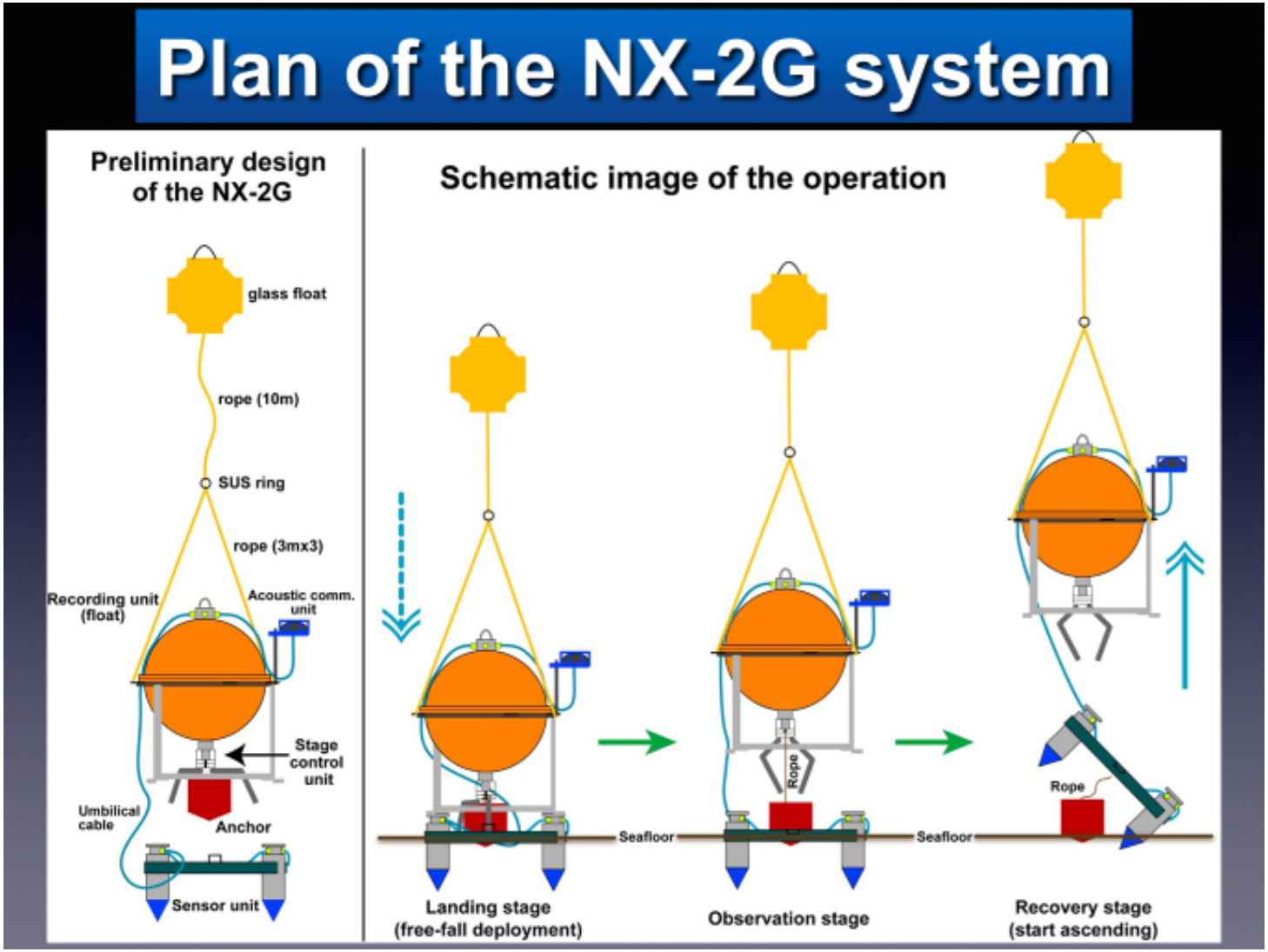
one day (2011/3/9) drum records of land, BBOBS-NX, BBOBS





NX: horizontal components are quiet

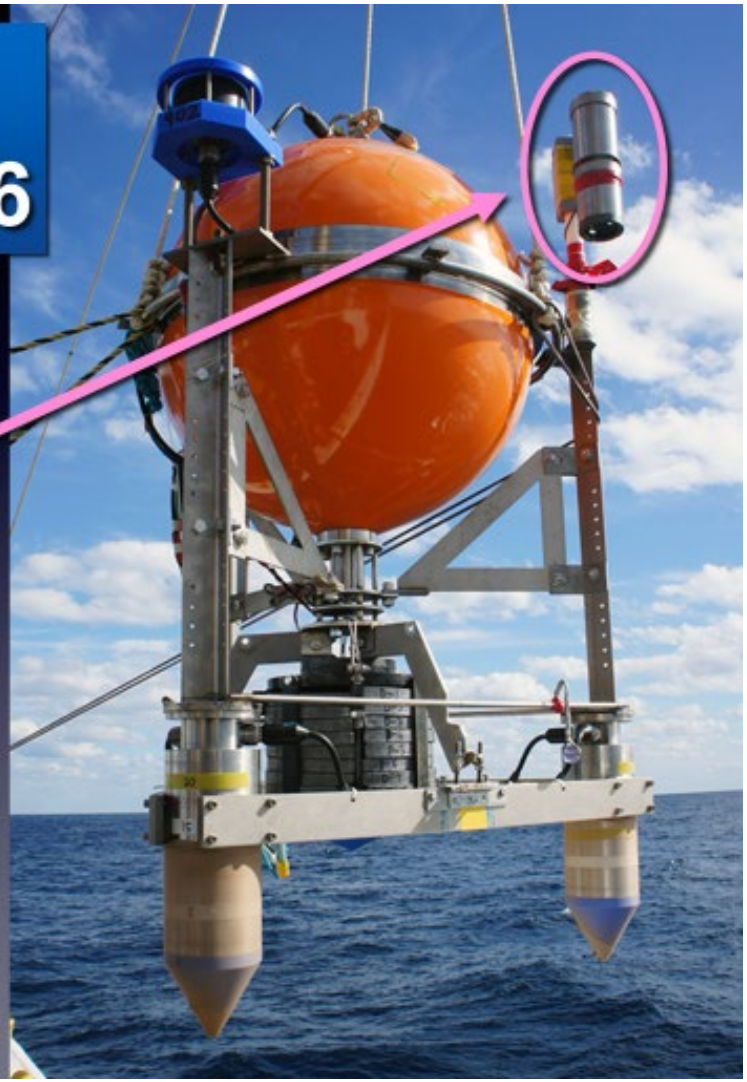
Plan of the NX-2G system



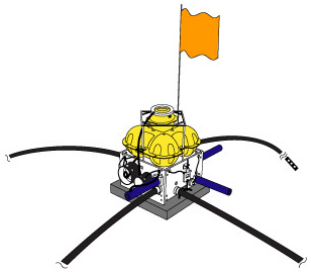
NX-2G prototype : 2016

To observe the tilting in descent and scene of landing, deep sea video cam and MEMS acceleration logger (inside of housing) were attached.

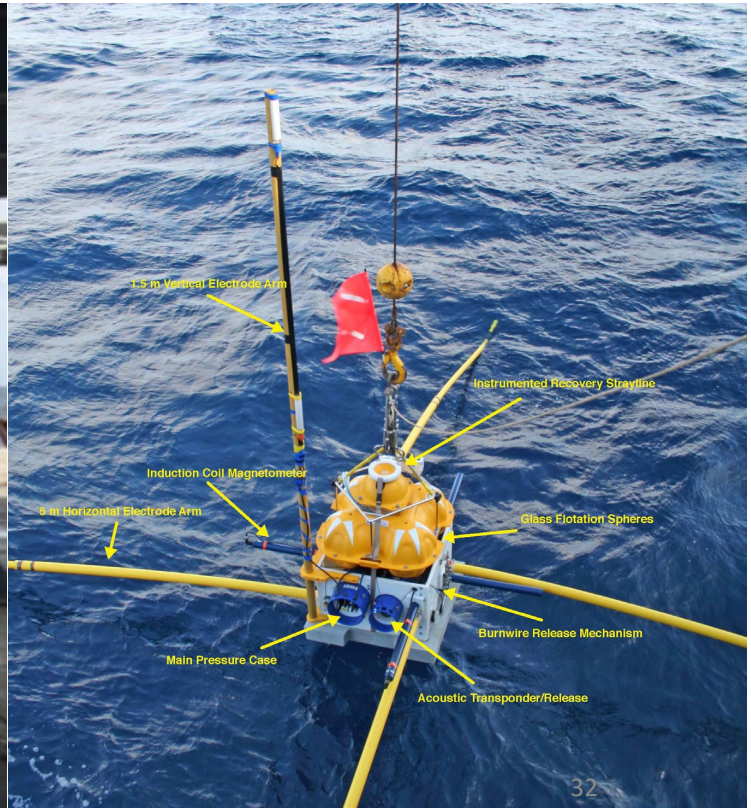
Additional glass floats for extraction force of the sensor unit were also expected to suppress the tilting in descent.



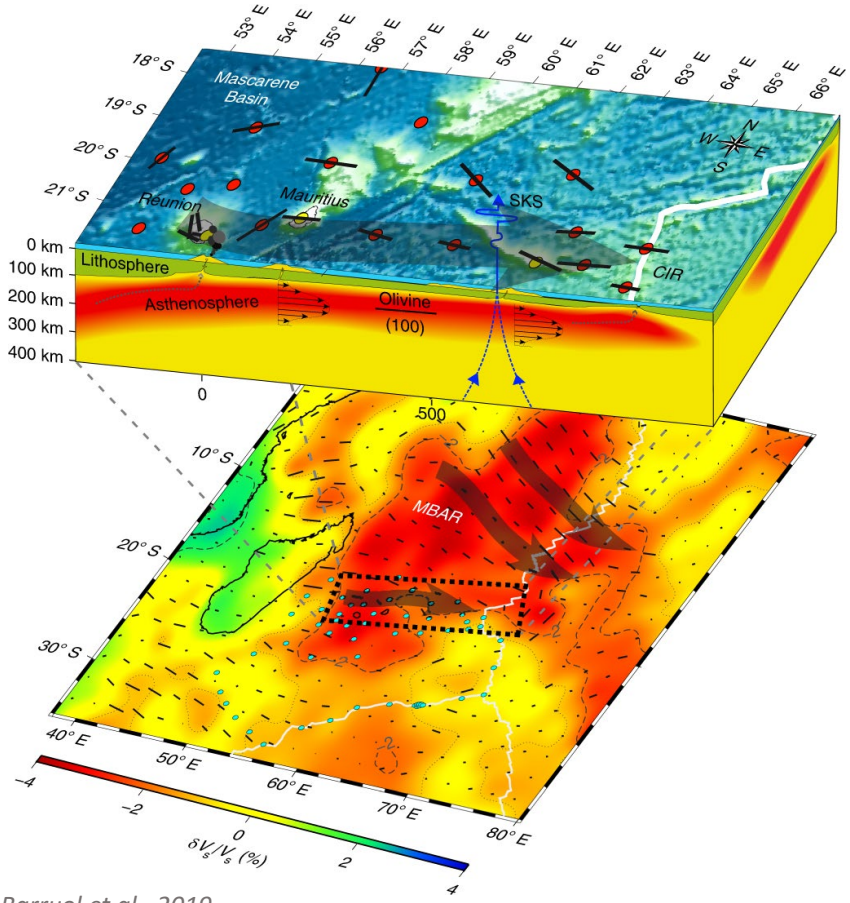
OBEM (Seafloor EM receiver) which measures conductivity



Channels	8 (MkIII), 4 (MkII)
ADC	24 bit
ADC noise floor	$10^{-13} V^2/Hz$ at 0.01 H to nyquist
Power consumption	450 mW (4 channels at 32 Hz sampling)
Maximum sample rate	1,000 Hz on 4 (Mk III) channels or 2 (Mk II)
Time base drift	1 - 5 ms/day, correctable to < 1 ms
E and B amplifiers	Chopper-stabilized
Bandwidth	10,000 s to 1,000 Hz
E sensors	AgCl electrodes
Voltage noise floor	$10^{-18} V^2/Hz$ at 1 Hz
E-field noise floor on 10m antenna	$10^{-10} V/m/sqrt(Hz)$ at 1 Hz
B sensors	Multi-turn, mu-metal core
B noise floor	$10^{-6} nT^2/Hz$ at 0.1 Hz
Weight of assembly in air	300 lbs
in water	-30 lbs
Endurance on one set of Li batteries	2 months
Data capacity	5 Gbyte (Mk III), 20 Gbyte (Mk II)
Depth rating	6,000 m
Acoustic navigation/release	SIO custom or EG&G
Long term loss rate	<2% per deployment
Deployments to date	>1,000

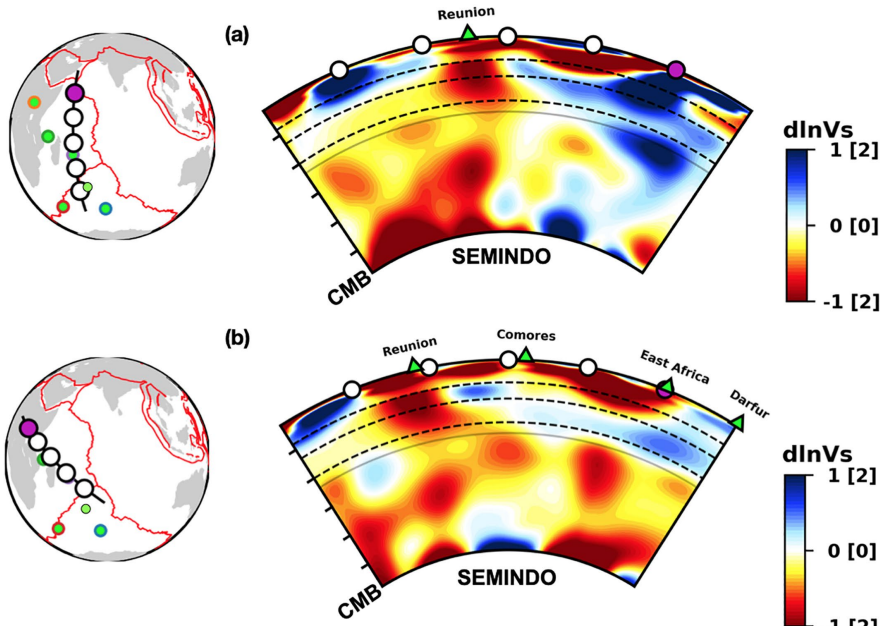


The Mascarene asthenospheric anomaly: a branch of the African plume tree?



From Barruol et al., 2019

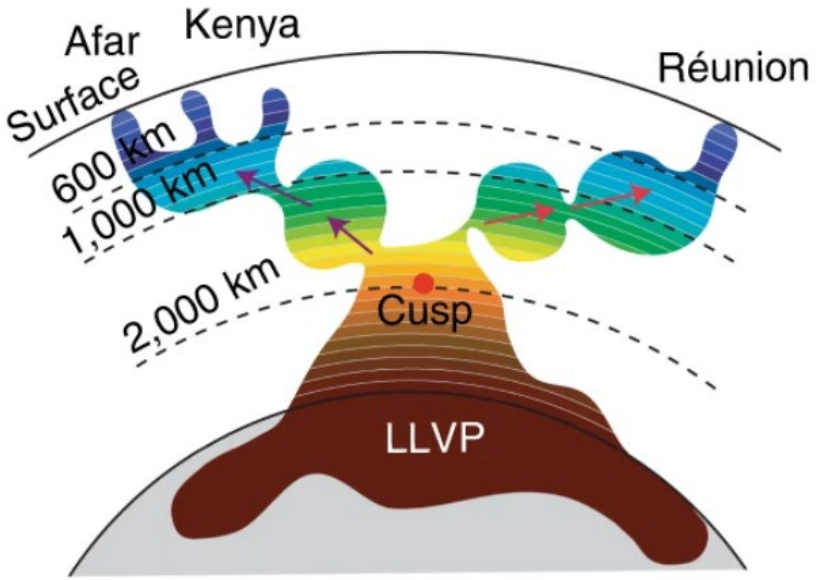
- **Barruol et al. (2019) highlight the presence of a plume-like anomaly under the Mascarene basin flowing to the southeast and passing under the Central Indian Ridge: the Mascarene Basin Asthenosphere Reservoir (MBAR).**
- **From a regional tomography study, Wamba et al. (2021) confirm the presence of the MBAR anomaly and show its connection to the lower mantle and the African LLSVP.**
- **Moreover, they show a low-velocity channel in the uppermost mantle connecting the MBAR, Comoros and East-Africa hotspots between them.**



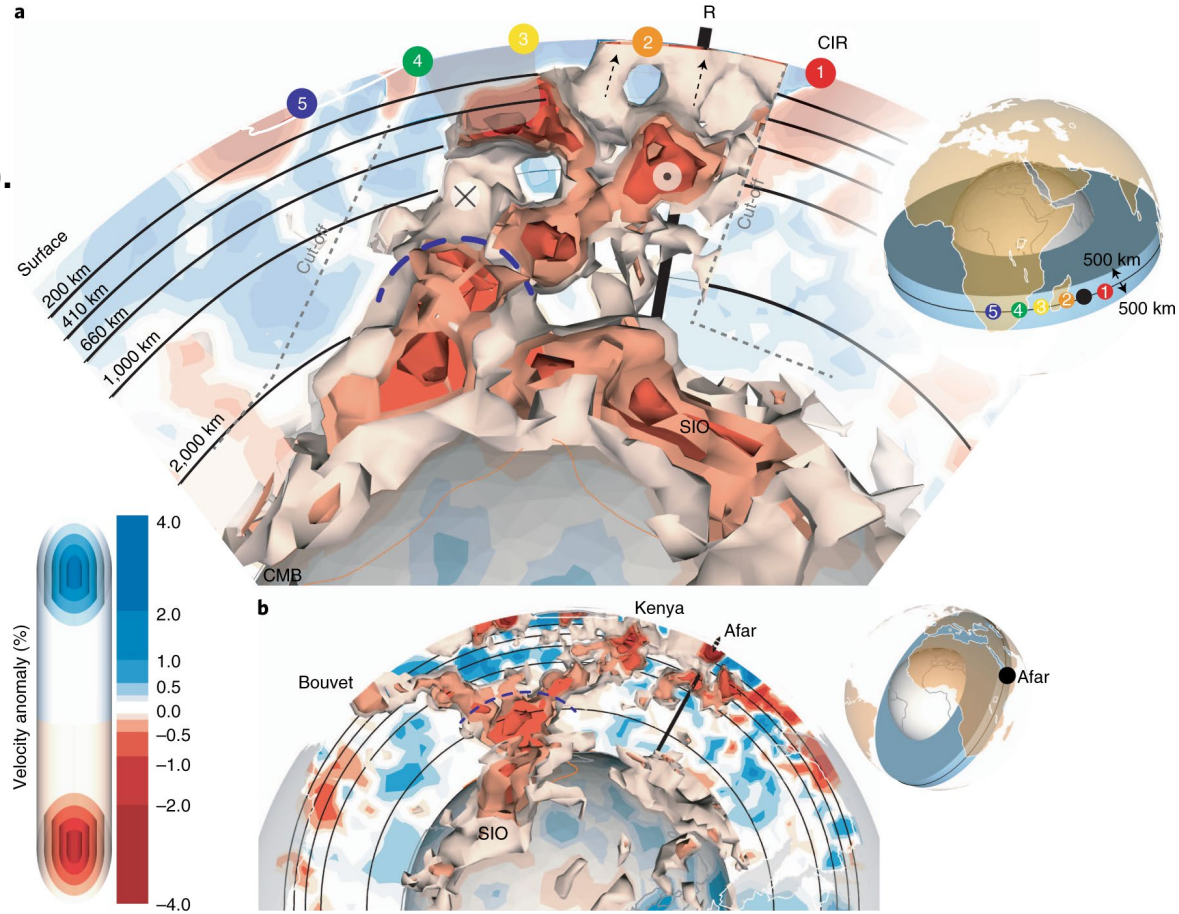
Section across the tomographic model of Wamba et al (2021)

The Mascarene asthenospheric anomaly: a branch of the African plumes tree?

- **The MBAR anomaly is probably a branch or a remnant of branch from the tree of Indo-African plumes presented by Tsekhmistrenko et al. (2021).**



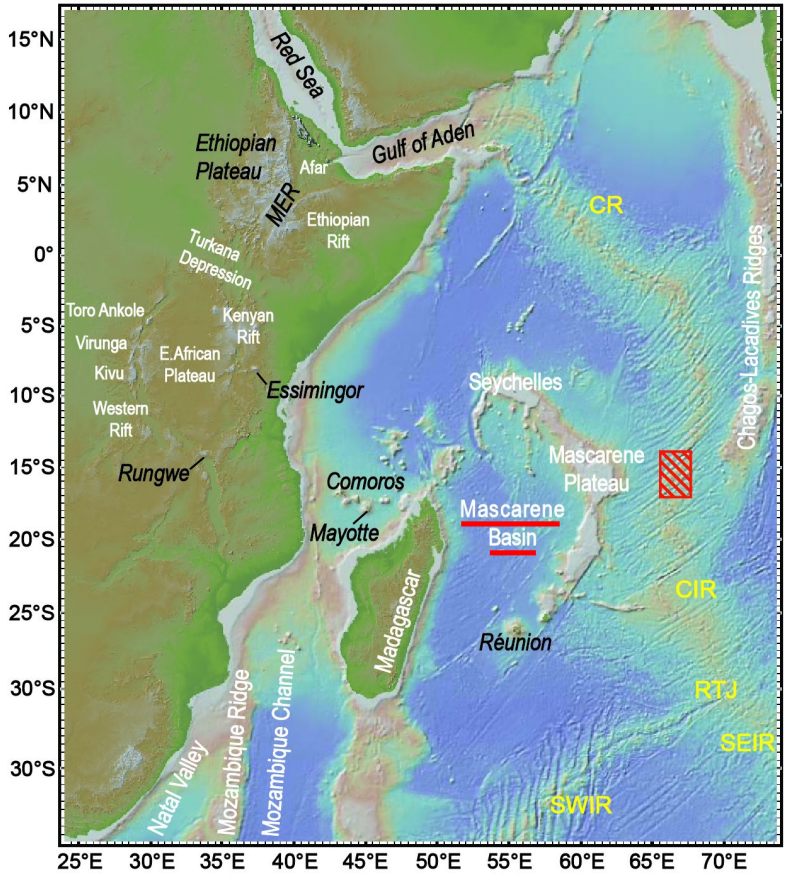
Conceptual cartoon of the plume tree, its East Africa and South Indian Ocean branch from Tsekhmistrenko et al. (2021, Nature geoscience)



3D rendering of slow P-velocity anomalies from Tsekhmistrenko et al. (2021, Nature Geoscience)

The Mascarene asthenospheric anomaly: a branch of the African plume tree?

- Geochemical analysis of MORBs present along the Central Indian Ridge show an enriched signature that can be related to the MBAR (study in progress).
- This geochemical signature seems to show a genetic connection with the different others plumes (Réunion, Comores, East-African rift …) considered to be linked to the African LLSVP, thus confirming the model of the African plume tree (study in progress).
- Further studies (Deep-seismic reflection, electromagnetic survey…) are needed to investigate the degree of interaction between the MBAR and the CIR as well as the geodynamic processes that link the different plume anomalies (Réunion , Comores, East African plume …) between each others in the Indian Ocean.
- Direct surface evidences of the MBAR activity like possible hotspots or seamounts in the Mascarene basin has yet to be found.

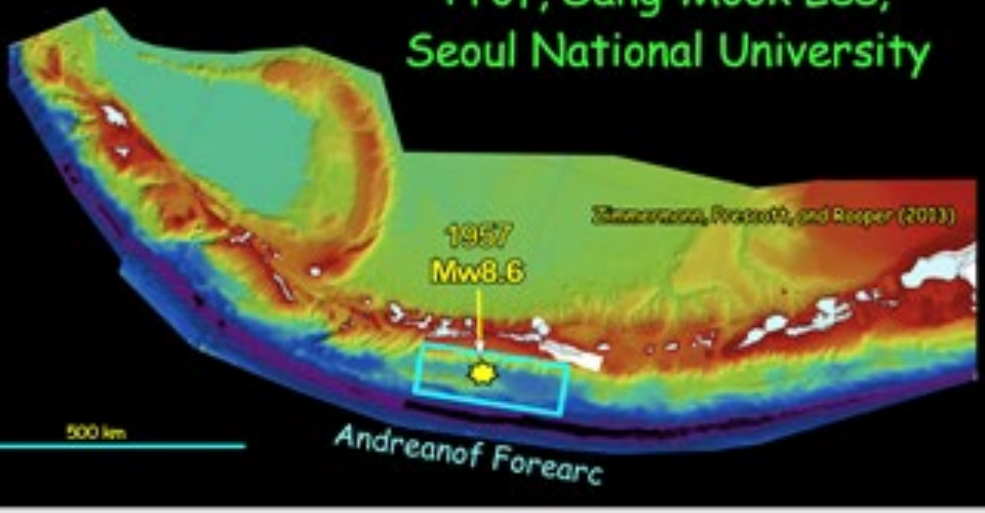


Location of the possibly influenced ridge portion by the MBAR anomaly

For The Aleutian Area, Acquiring Target-area Multibeam Maps and Seismic Lines to Address Scientific Questions is a Challenging Funding and Operational Enterprise.

Through the Efforts of Prof. Sang-Mook Lee, Seoul Nat. Univ., Korean State-of-the-art Research Vessels Might Become Available to Assist Future Aleutian Bathymetric and Seismic Studies.

Prof, Sang-Mook Lee,
Seoul National University



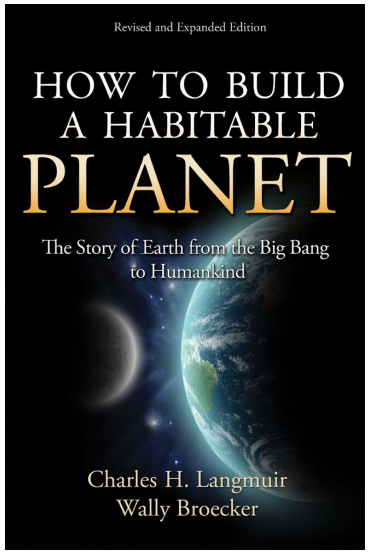
Korean Icebreaker,
R/V Araon

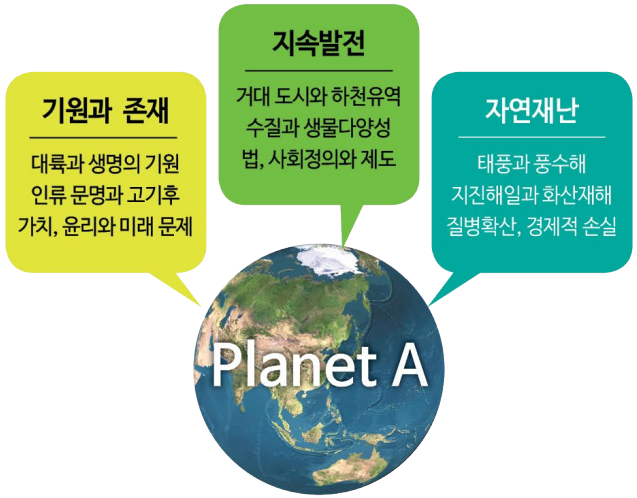
Korean 2D Seismic Vessel,
Tamhae II

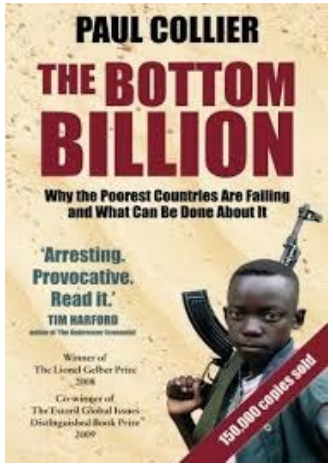
Korean 3D Seismic Vessel,
Tamhae III

Planet A: Investigation of Origins, Sustainability and Risks of Our Planet

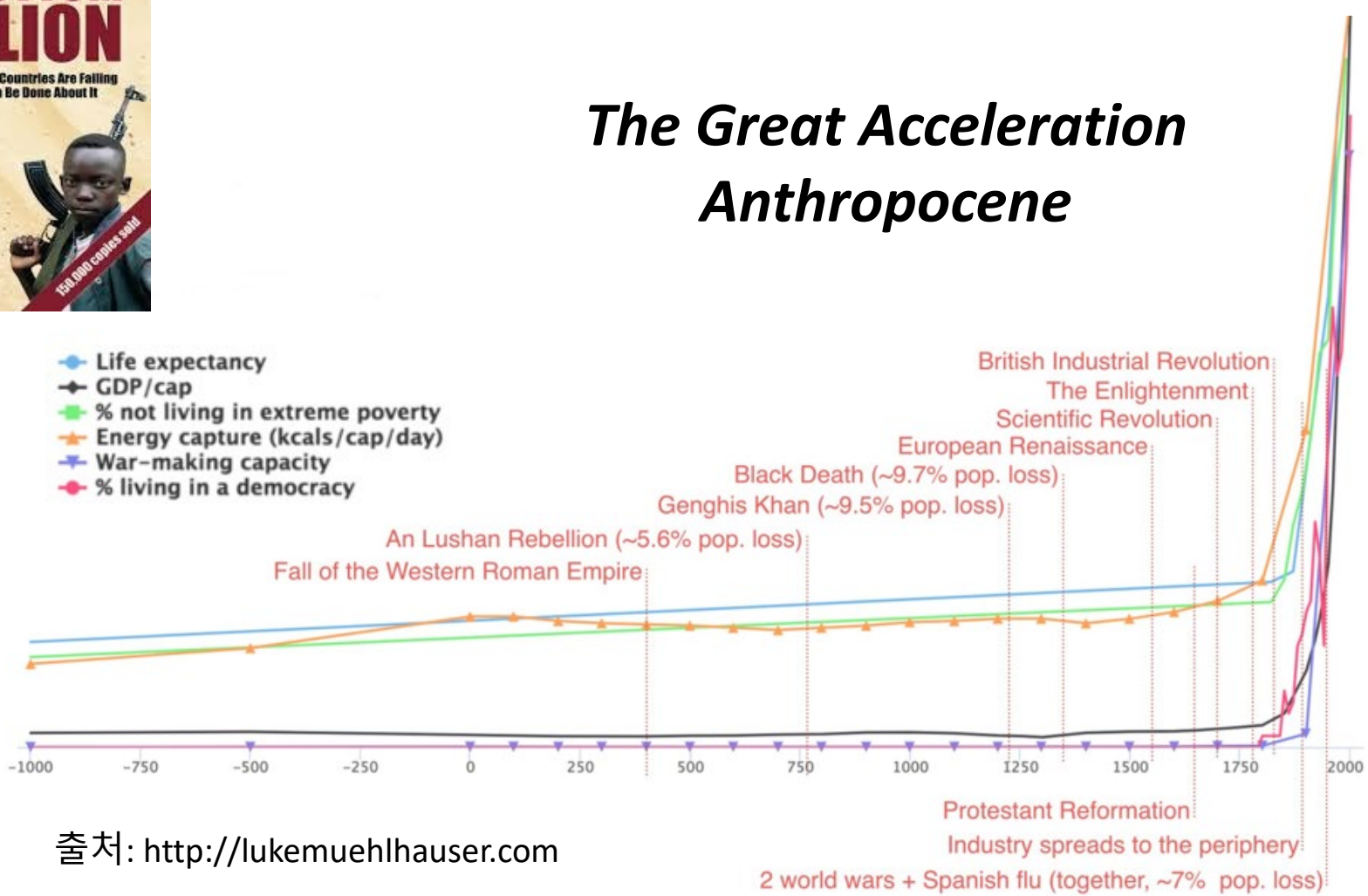
This led to 10-10 Initiative by Seoul National University where our School of Earth and Environmental Sciences was chosen among the 10 disciplines with myself as the PI.





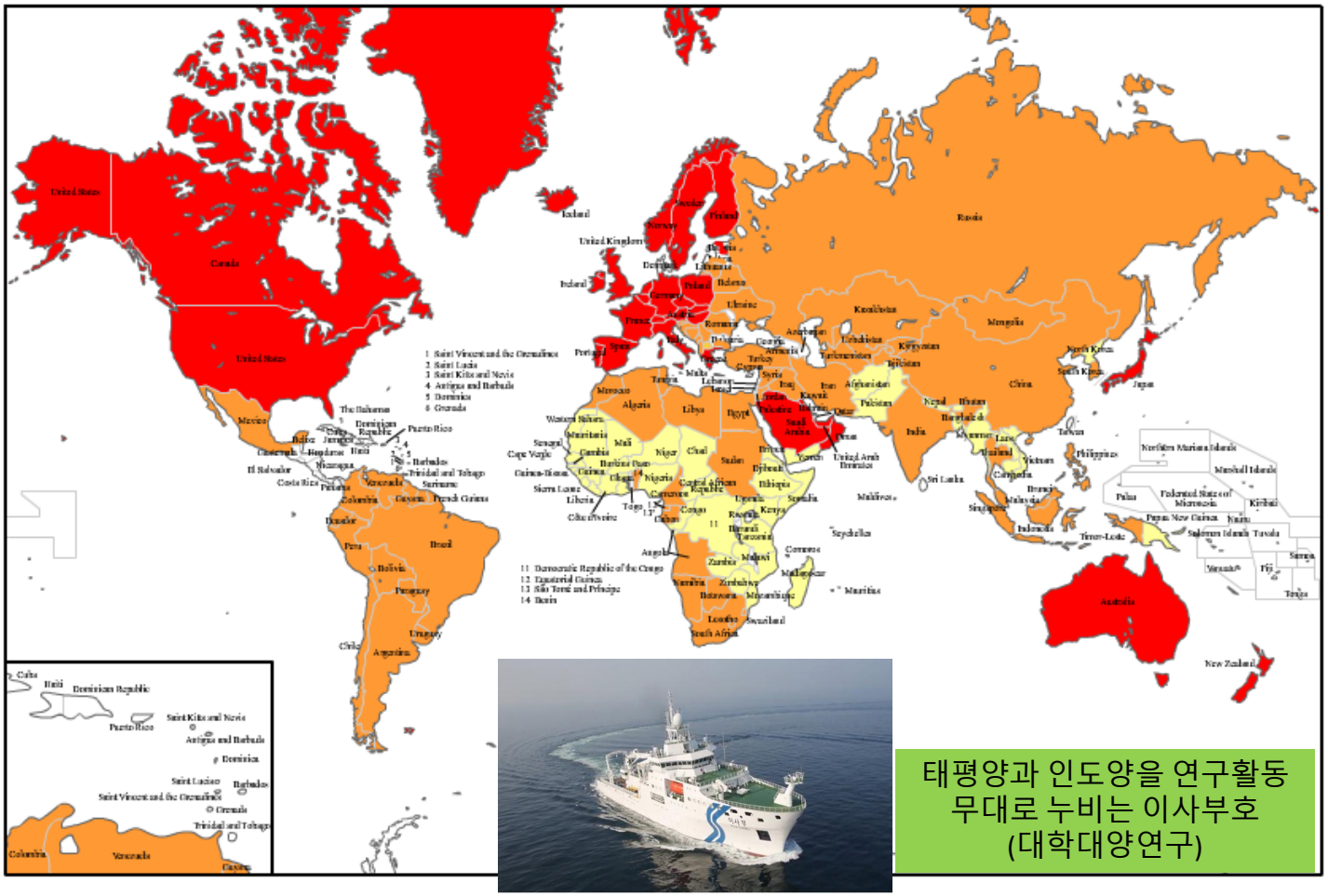


The Great Acceleration Anthropocene



출처: http://lukemuehlhauser.com

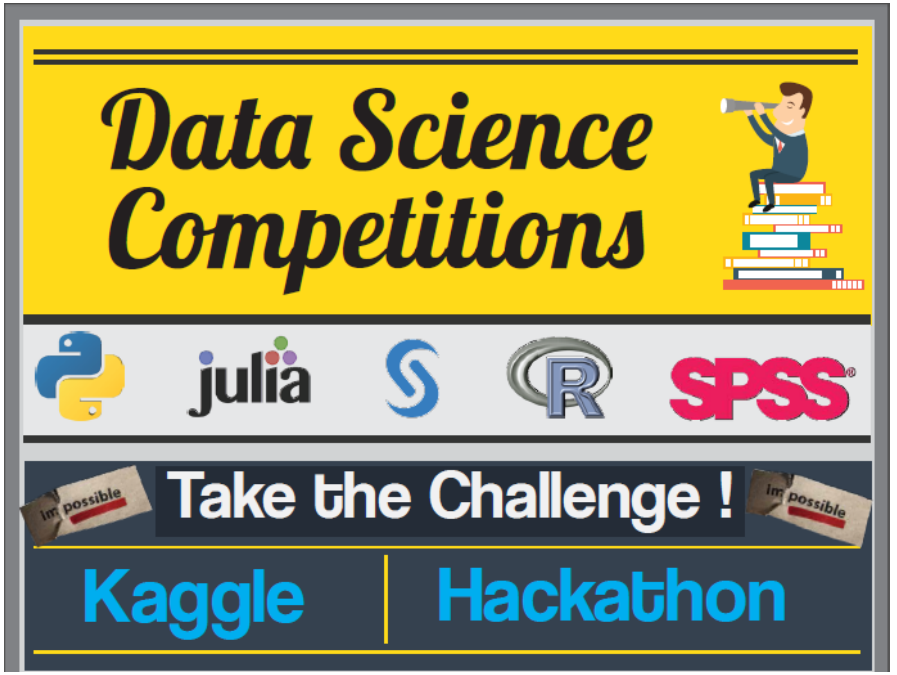
Countries with yellow color represent the bottom billion



태평양과 인도양을 연구활동 무대로 누비는 이사부호 (대학대양연구)

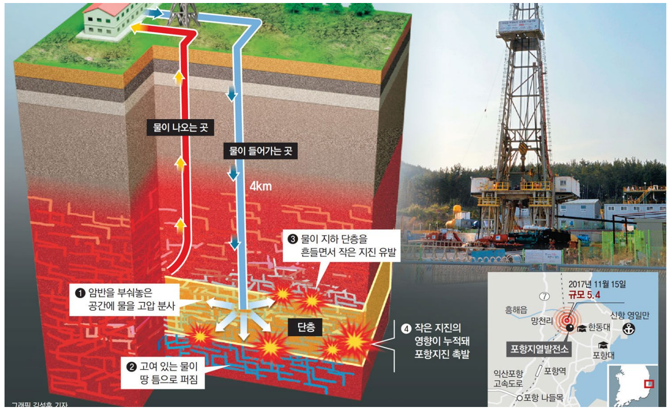
출처: http://fairtrade-eerlijkehandel.blogspot.kr

Using global data hub, solve societally important Earth science issues.



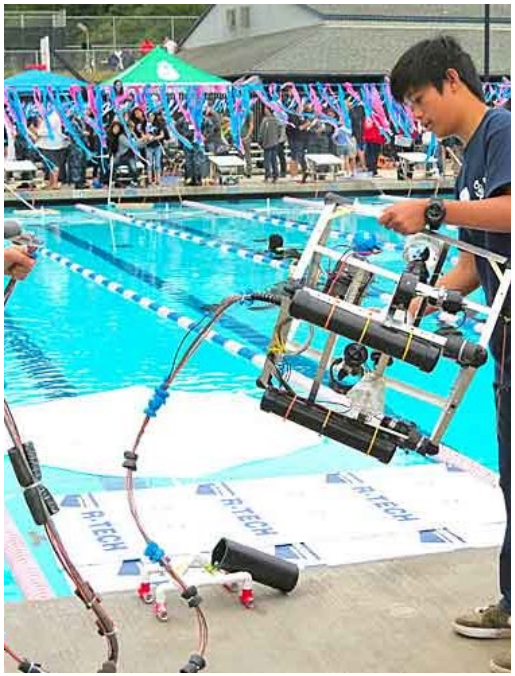
SK E&S

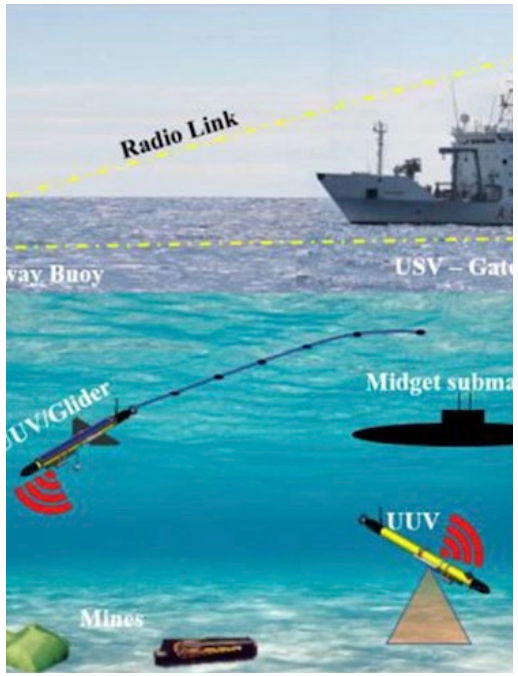
District Energy
집단에너지사업
City Gas
도시가스사업
Renewable Energy
신재생에너지사업
Global Business
해외사업
Renewable Energy
SK E&S는 신재생에너지 사업을 통해 미래를 준비합니다.



물이 나오는 곳
물이 들어가는 곳
4km
❸ 물이 지하 단층을 흔들면서 작은 지진 유발
❶ 암반을 부숴놓은 공간에 물을 고압 분사
단층
❹ 작은 지진의 영향이 누적돼 포항지진 촉발
❷ 고여 있는 물이 땅 틈으로 퍼짐
2017년 11월 15일
규모 5.4
흥해읍
망천리
신항 영일만
한동대
포항지열발전소
포항대
포항역
익산포항 고속도로
포항 나들목

Being able to develop the next generation of geophysical instruments are so important for cutting-edge research





OPEN SOURCE HARDWARE PROJECT CONTEST 2020

Inspiring young children (ages 10 - 15) with disability into science (ROPOS Project)

ARDUINO Raspberry Pi

International Union of Geodesy and Geophysics
IUGG
UGGI
Union Géodésique et Géophysique Internationale
Centennial | 1919-2019 | Centenaire

33rd Conference on Mathematical Geophysics

Geophysics in the World of Modern Mathematics and Artificial Intelligence

Postpone to summer of next year 2022 in Seoul Korea

Mark Your Calendar!!