



The Science of Prediction

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Can We Predict the Future ? (1)

- Art of God
- Fortune-telling or magic ritual
- Experience—weather lore, sailing (voyage at seas)
- Hiyoriyama, Hiyorimi
- Weather forecast, from experience to science
- Numerical estimate



Can We Predict the Future ? (2)

- Can we predict the future ?
- An inch ahead is darkness !
- Many things are unknown and impossible!
- Weather is a physical phenomenon. There are principles, and prediction is possible !
- L.F.Richardson's challenges(1922)
- Richardson's dream

Richardson's Dream (1)

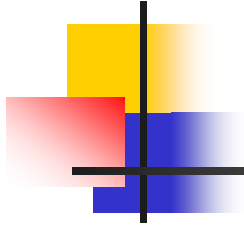
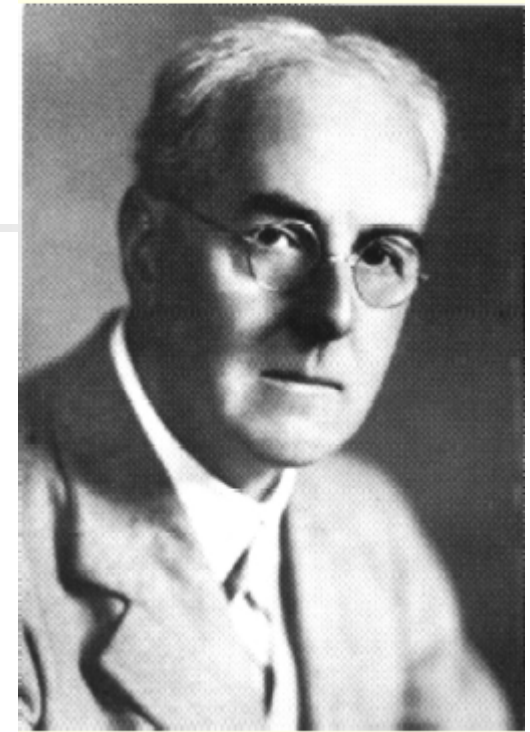


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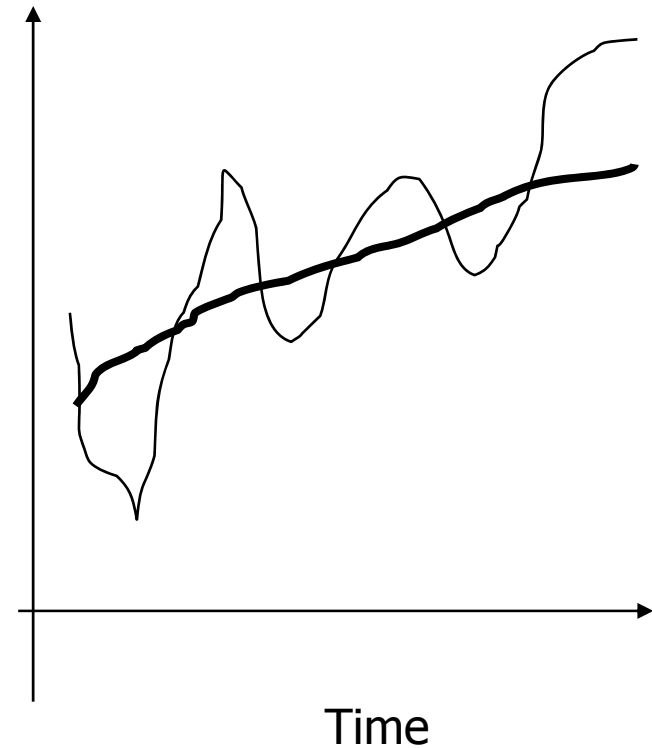
Tomorrow's weather can be
predicted by calculation!



Richardson's Dream (2)

- Richardson's efforts for years ended in failure.
- The result was 100hPa decrease in surface pressure in 6 hours. In fact, he did not make calculations for 6 hours.
- There were various rules of nature.
 - activities on a fast time scale and
 - activities on a slow time scale

Surface
pressure



Richardson's Dream(3)

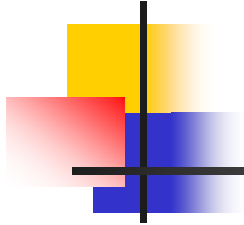
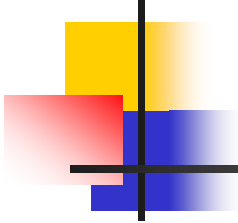


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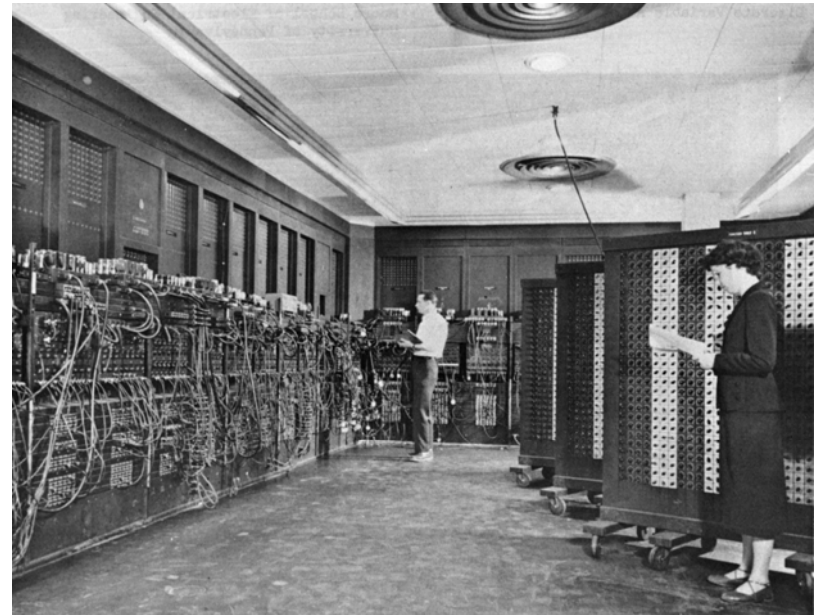
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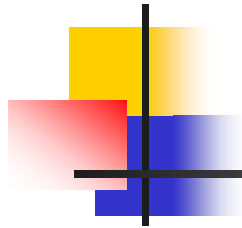
Lessons From Richardson's Dream

- 
- Without enough understanding, it will end in failure.
 - Without tools to realize an idea, it will end in failure.
 - But if you don't try, you won't fail either
 - Based on the lessons from this failure, the development of computer and numerical forecasting and numerical simulation advanced.

Based on the Lessons

- Development of computers (von Neumann computer)
- ENIAC
- Establishment of new dynamic framework (Quasi-geostrophic study)
- GFD: Establishment of Geophysical Fluid Dynamics





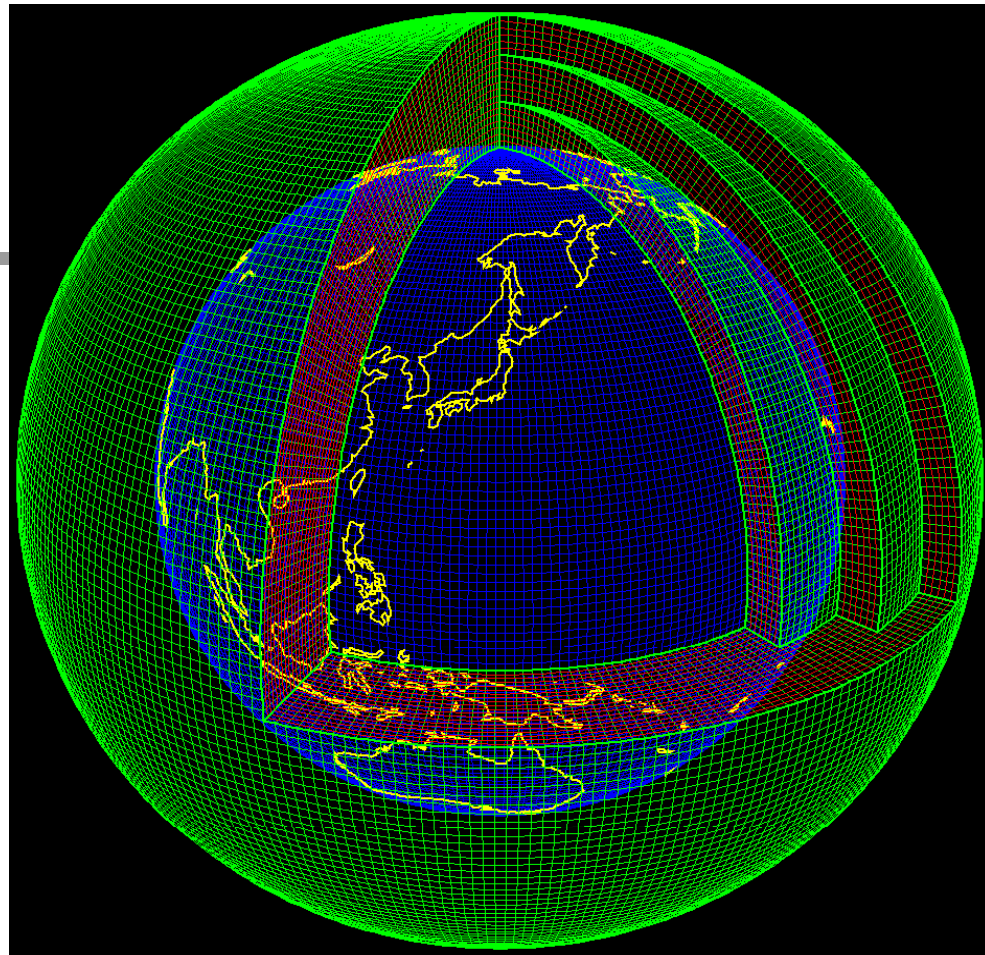
The Climate Model

- The climate system is composed of various subsystems.
- Grid points are located all over the Earth, and variables which indicate physical values are set for each point.
- Changes of physical values are indicated by physical laws and empirical rules.
- Temporal integration by numerical calculation

The Climate Model



Grid-points are located all over the Earth, and wind, temperature and cloud are calculated.





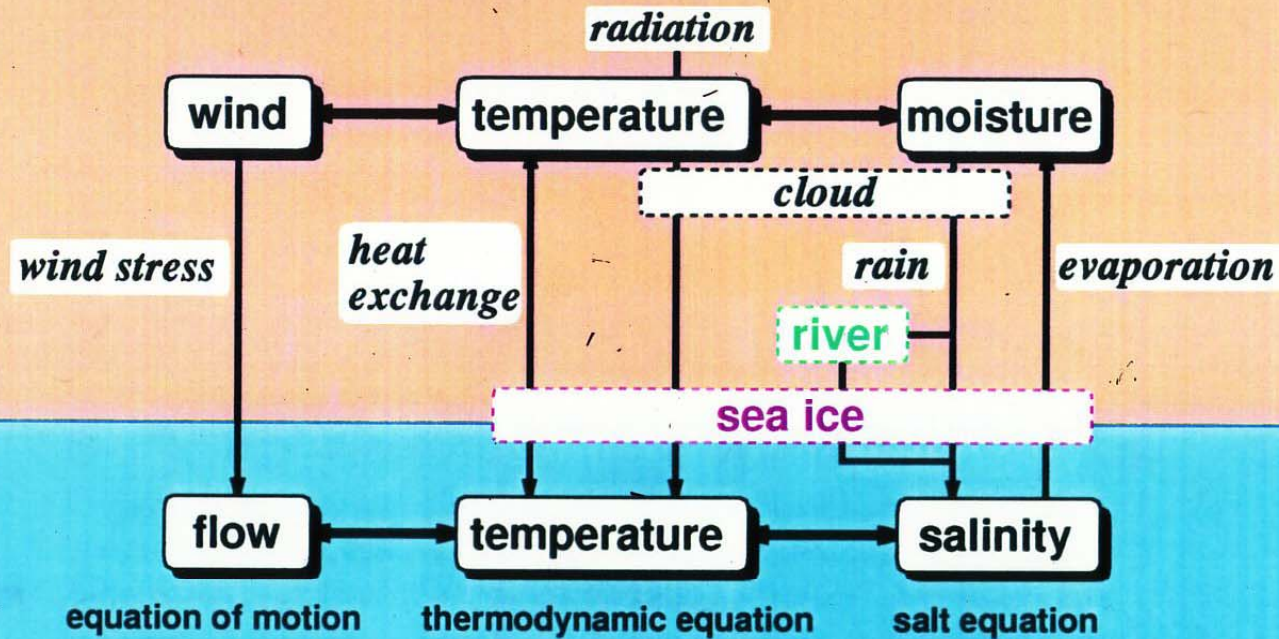
Conservation Formula

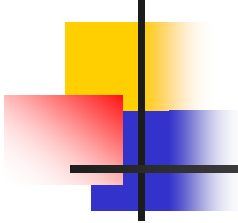
- Conservation of momentum
- Conservation of mass
- Conservation of energy

$$\frac{\partial X}{\partial t}$$
$$+ \nabla \cdot X = \text{Source} - \text{Sink}$$
$$\frac{\partial X}{\partial t}$$

Coupled Ocean-Atmosphere GCM (COA-GCM)**Atmosphere GCM**

equation of motion thermodynamic equation
radiative transfer equation equation of water vapor

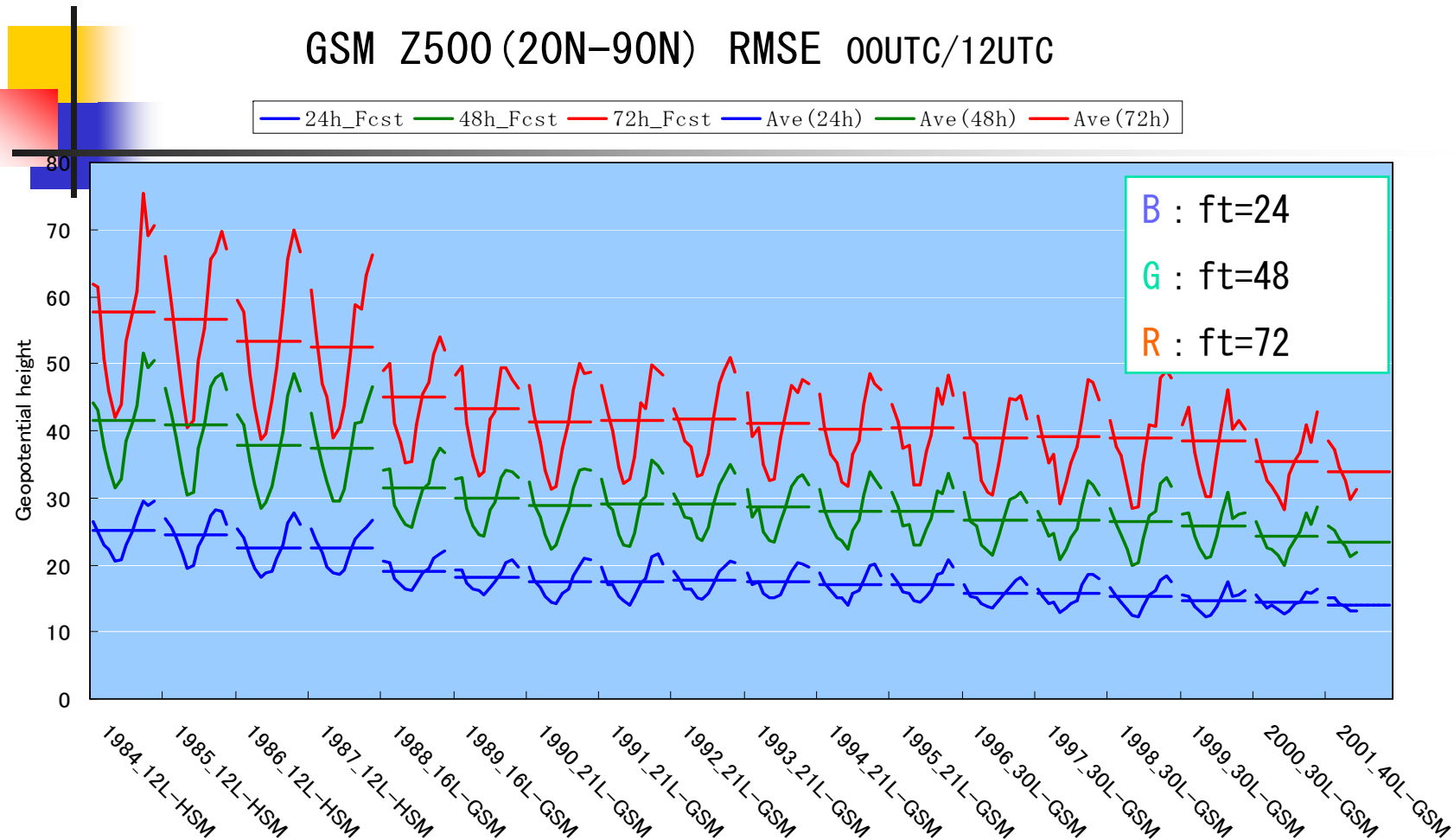




Super-Computer-Promoted Weather Forecasting

- NWP—ENIAC(1948?)
- ECMWF—CRAY1(1979)
- The Earth Simulator
- In Meteorological Agencies
- Since the IBM704, super computer was introduced, the accuracy of weather forecasting has increased.

2. Cloud and Convection in the Global Model



88.3, 89.11 Model change

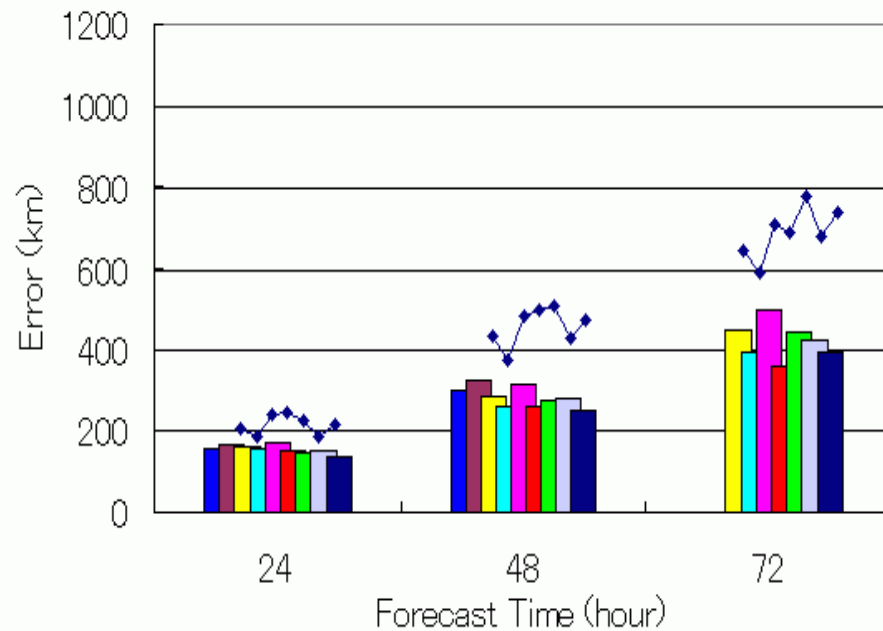
96.3 Arakawa-Schubert scheme

99.12, 01.03 Revise Arakawa-Schubert scheme

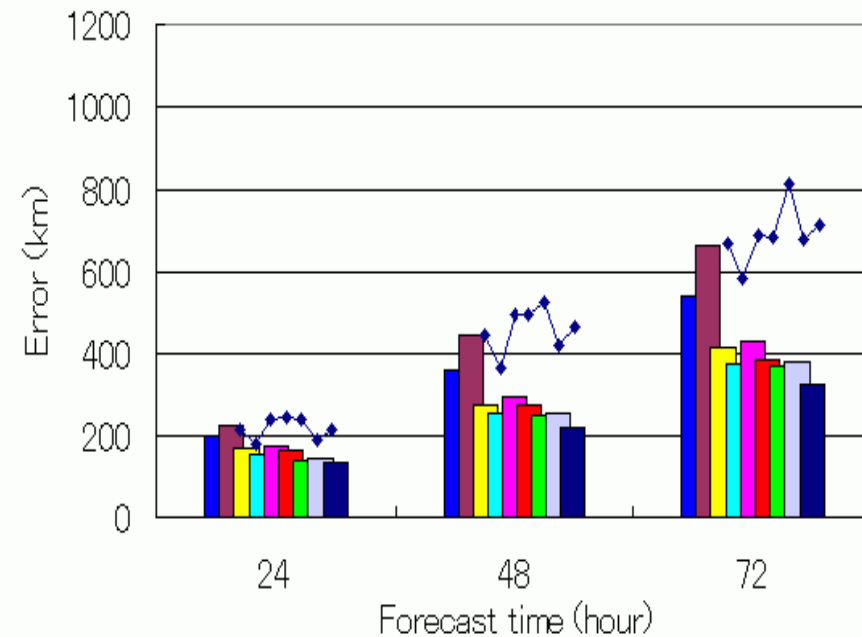
† Source: Japan Meteorological Agency

Position Errors of TC Track Forecast by TYM and GSM

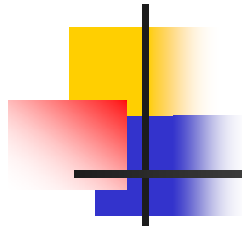
TYM Mean Position Error 1994 -2002(τ_{0222})



GSM Mean Position Error 1994 -2002(τ_{0222})



■ 1994 ■ 1995 ■ 1996 ■ 1997 ■ 1998 ■ 1999 ■ 2000 ■ 2001 ■ 2002



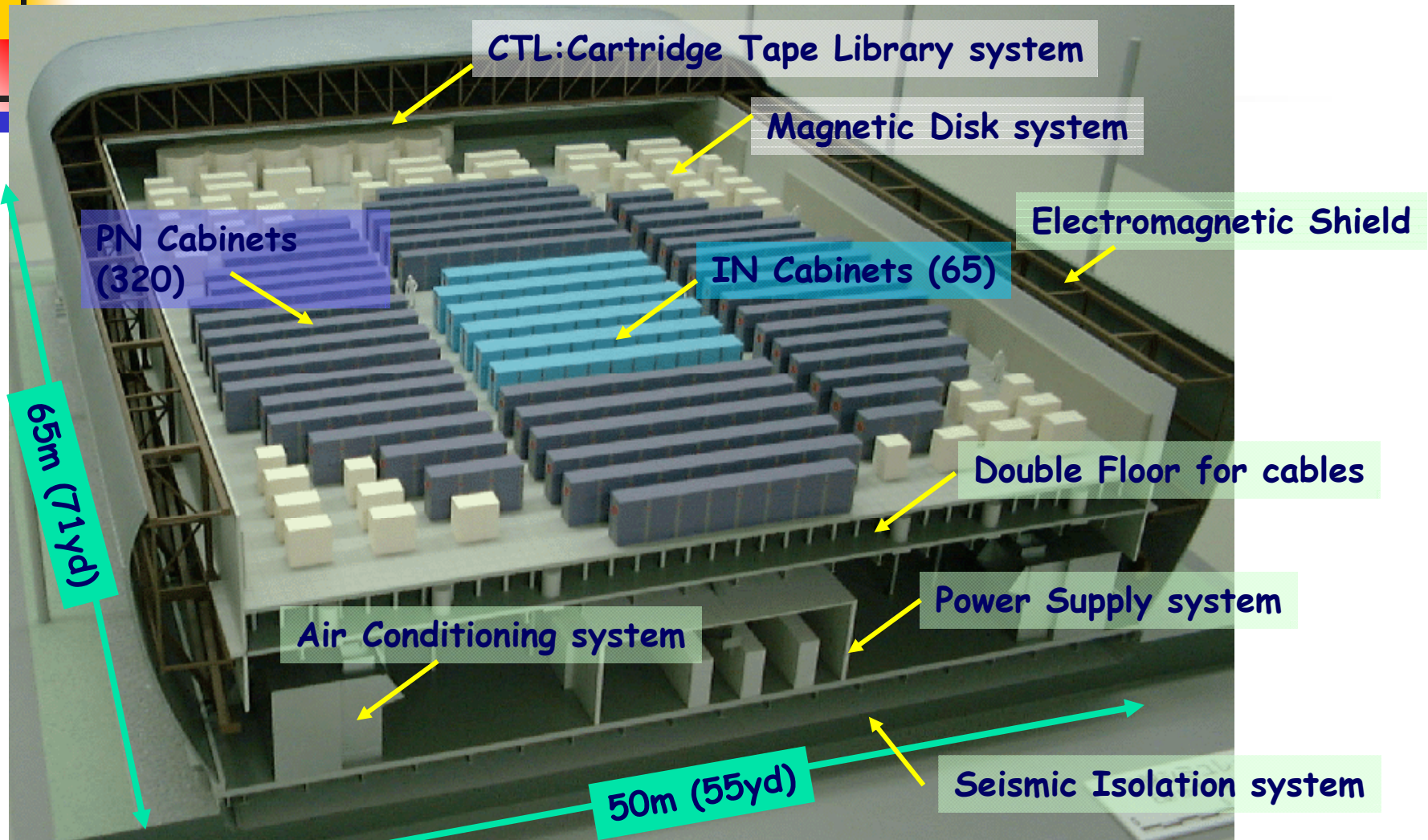
The Earth Simulator

- 5-year project from 1997 to 2002 !
- Vector-Parallel
- Many criticisms within the country
- There were global impacts which changed values and the age in foreign countries.
- Software development took place at the same time !

The Earth Simulator



† Source: Japan Agency for Marine-Earth Science and Technology



† Source: Japan Agency for Marine-Earth Science and Technology



The Earth Simulator Center

† Source: Japan Agency for Marine-Earth Science and Technology



Weather

- Interaction between clouds, rain and solar radiation
- Expression of clouds
- Resolution performance of several 100 meters is needed.
- Region model ——> Globalization

TL1023L40 Typhoon Forecast

(09 Jul 2002 00UTC, FT=24, GSM-IR forecast images)

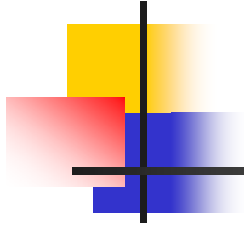


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20km-GSM TL1023L40 2002.7.9.00Z FT=24

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GMS-5 obs. 10 Jul 2002 00UTC

Cloud Image

15JST 14 JAN. 2001



GMS-5 :
Visible-Image

1km-NHM :
Total Water Path

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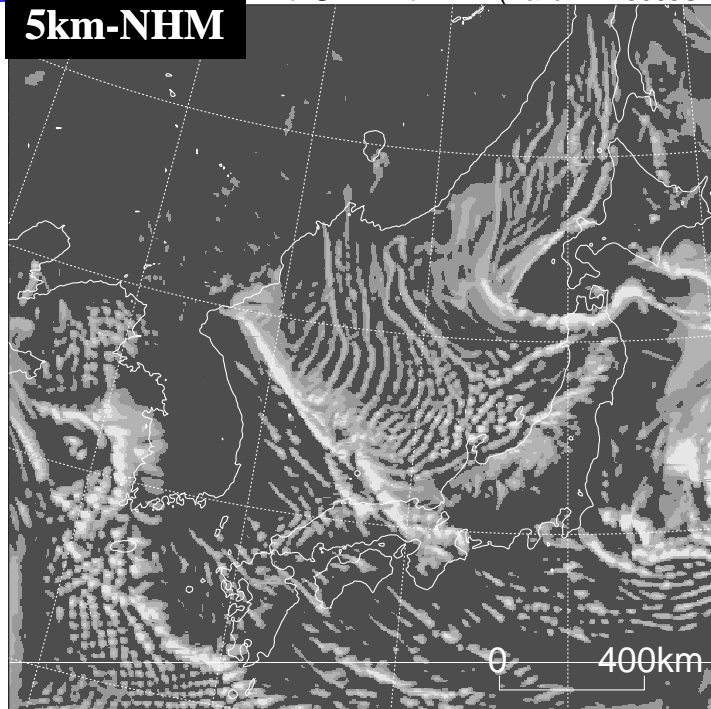
- The 1km-NHM successfully reproduced cloud bands extending southeastward from the base of the Korean Peninsula to the San-in and Hokuriku district over the Sea of Japan.
- Several cloud streets were also calculated around cloud bands.

Dependence by the Horizontal Resolution

Total Water Path : 5 hour forecast :15JST 14 JAN. 2001

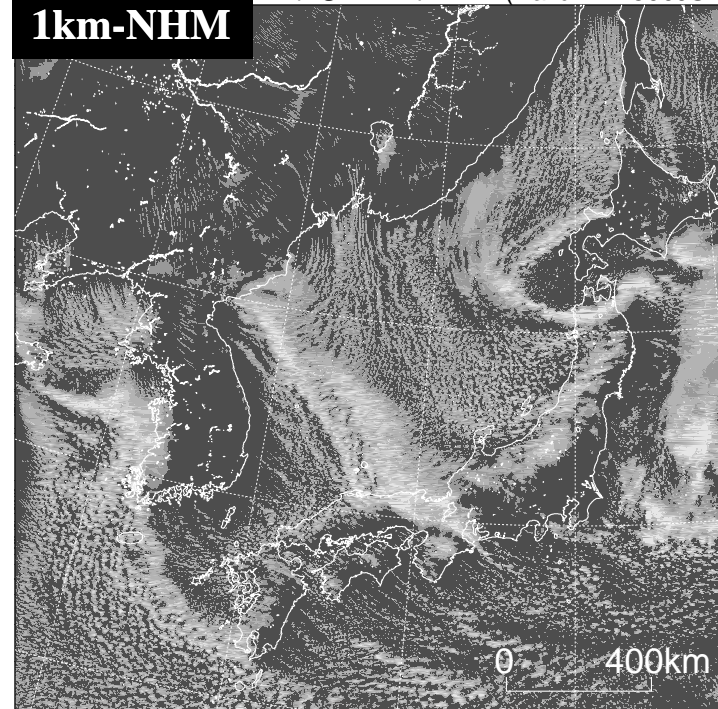
Total Water Path (kg/m/m) 5hour 0min
(Valid:14.1500JST)

5km-NHM



Total Water Path (kg/m/m) 5hour 0min
(Valid:14.1500JST)

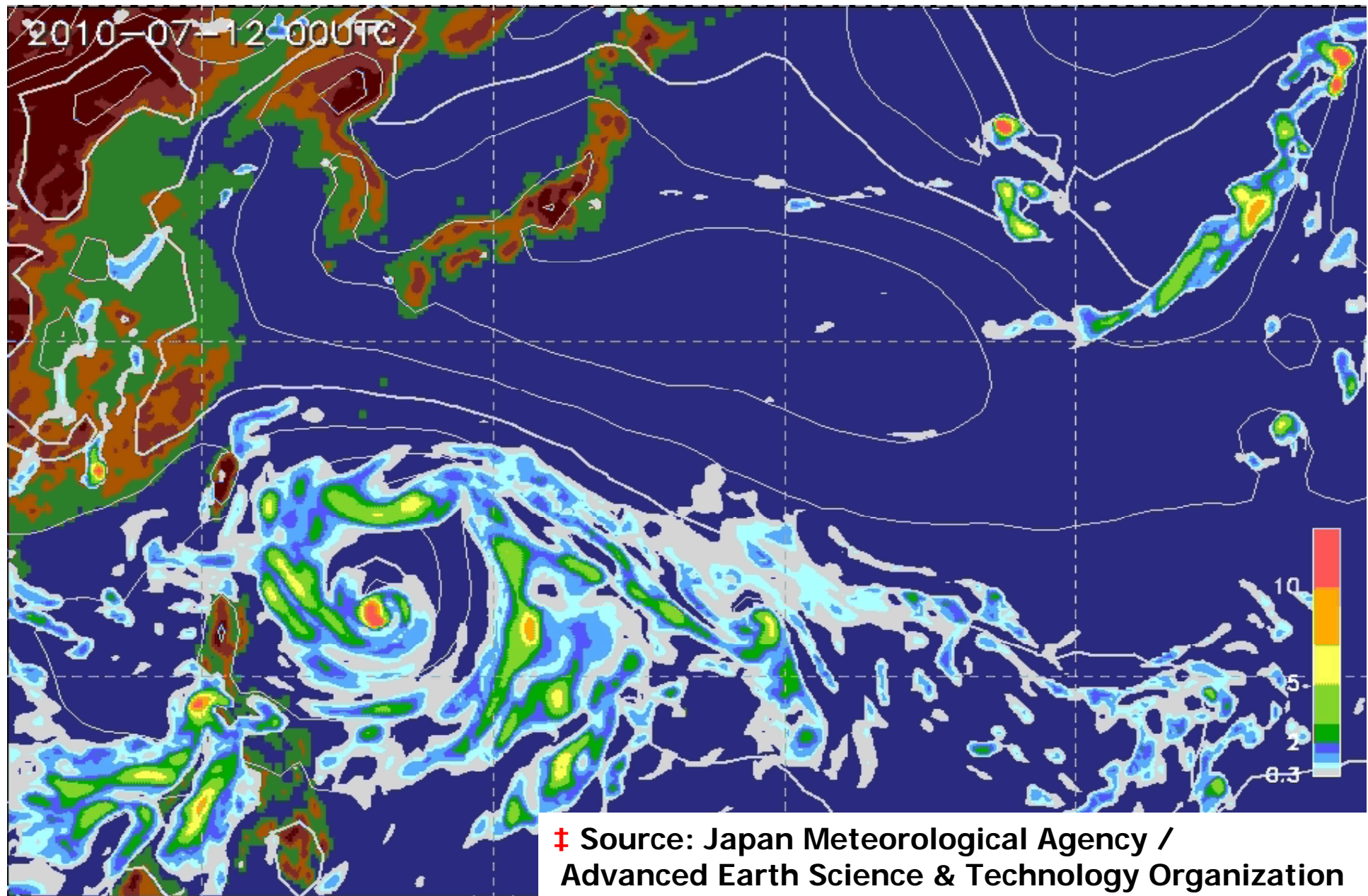
1km-NHM

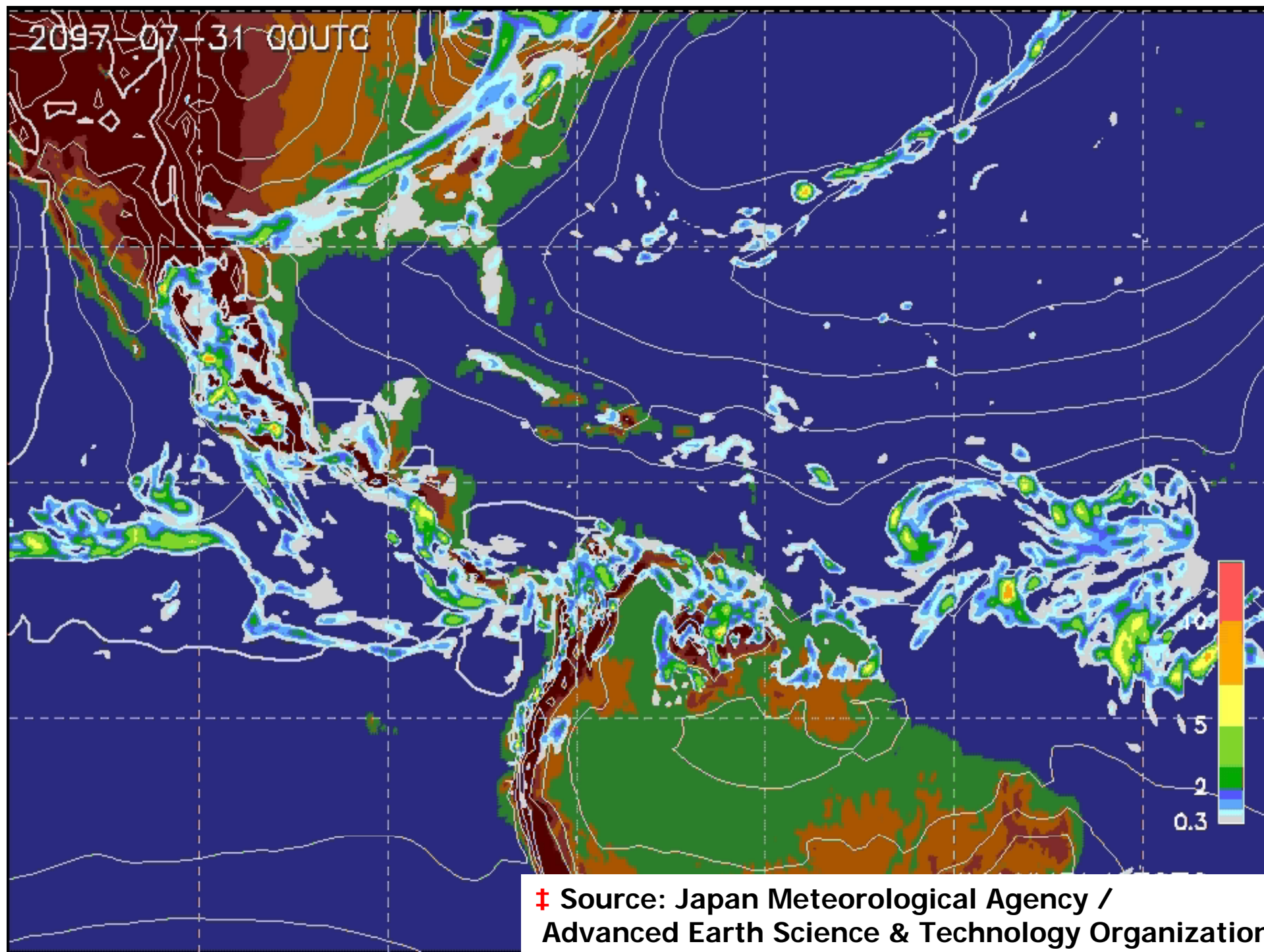


● The 5km-NHM also well reproduced the features of cloud bands and other clouds

● More detailed features have been well reproduced by 1km-NHM.

An extremely intense typhoon appears in the future expt. (AS)
with MIROC Δ SST (max sfc wind 68.8 m/s, CP 877.6 hPa)







You Cannot Predict the Future Only by Model!

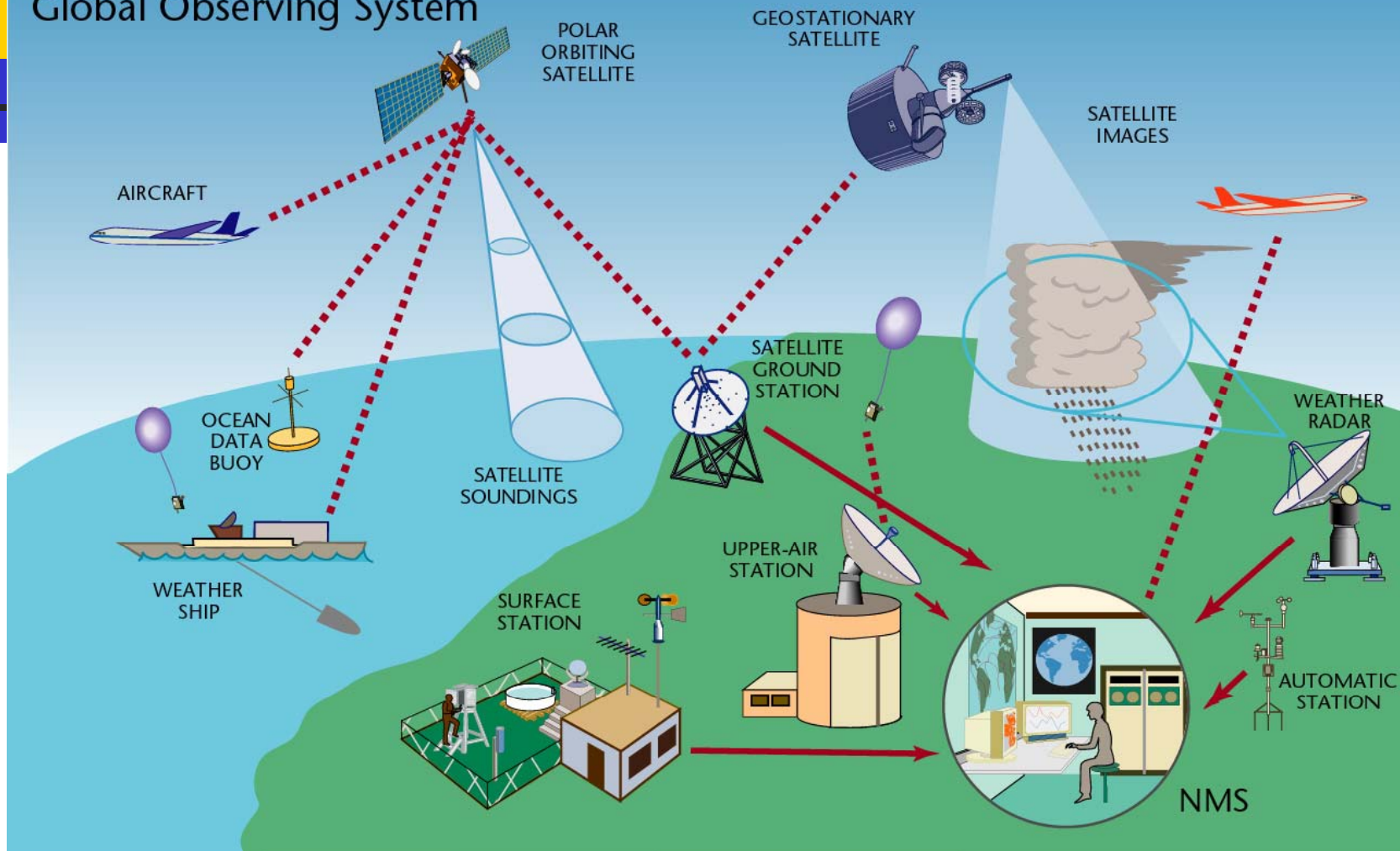
- Present state must be known !
- There is a need for observation of the Earth.
- International cooperation is essential.
- International cooperation is especially needed in weather forecasting.
- WMO (World Meteorological Organization) and WWW project.



From Observation of Weather to Observation of Climate

- GOS(Global Observing System)
- GCOS(Global Climate Observing System)
- GOOS(Global Ocean Observing System)
- GTOS(Global Terrestrial Observing System)
- GEOSS(Global Earth Observing System of Systems)

Global Observing System

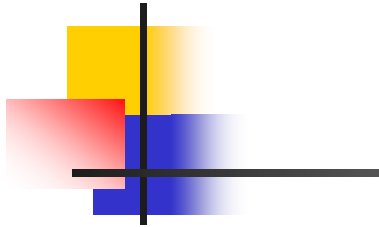


† Source: World Meteorological Organization



Global Awareness is Important !

- The Earth is big. There are many regions where observation is difficult.
- In the past, expeditions and special observations were conducted.
- However, science and technology are constantly developing.
- We could not observe the Earth in the past.
- Now, the Earth can be seen easily on TV!



Wikipedia

Humans seized the power of God!



Satellite Observation Data ...

- Would be the basis for creating a sustainable society in the 21st Century.
- Link with data — > popularization of information
- For example ...
- Logging in tropical rainforest —fish-bone???????????
- Ozone-holes



✚ Source: Ministry of Education, Culture, Sports, Science and Technology Japan

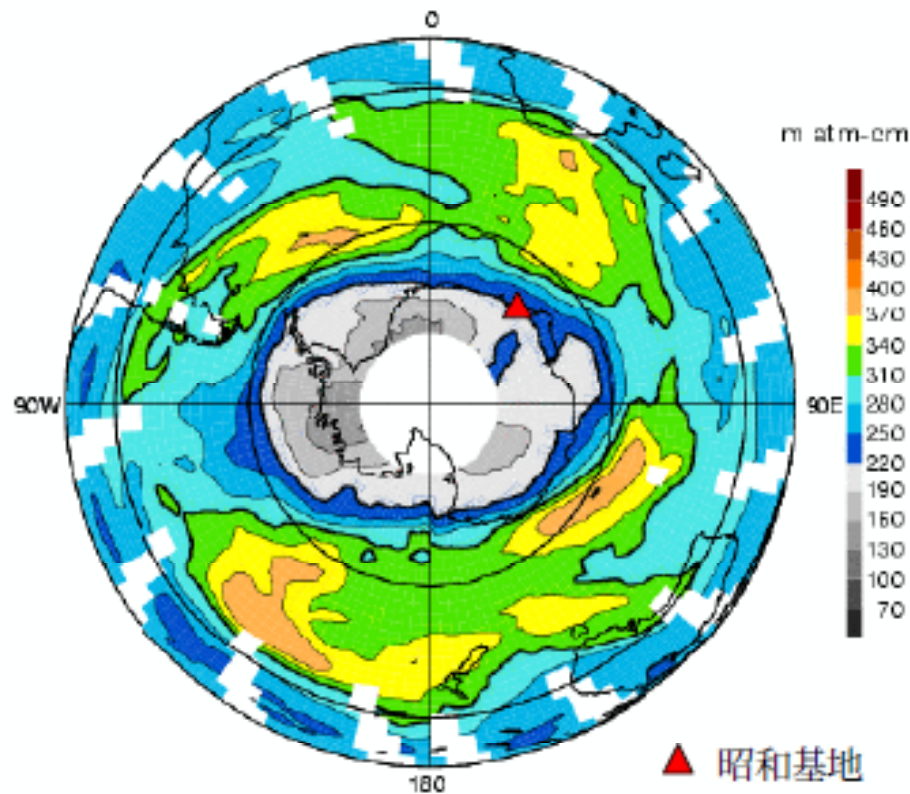


Fig.1 Southern hemisphere ozone distribution (Sept 8)

Ozone data from TOMS (Total Ozone Mapping Spectrometer) equipped on Earth Probe Satellite of the USA (NASA)

† Source: Japan Meteorological Agency made from the data provided by NASA

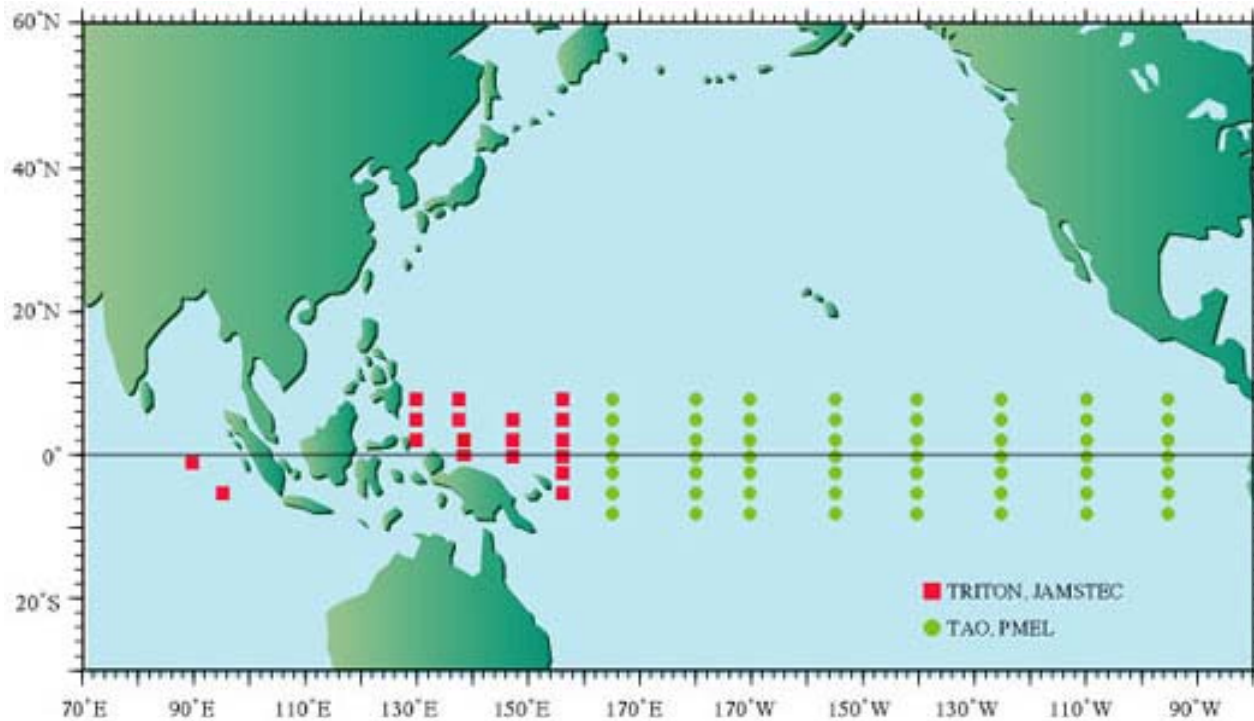


Not Everything Can be Understood by Observation From Space

- The ocean covers 70% of the Earth's surface.
- Electric waves are not transmitted in the ocean.
- There are many places on Earth where there are no inhabitants.
- Remote sensing data cannot be used without checking by observation from Earth.

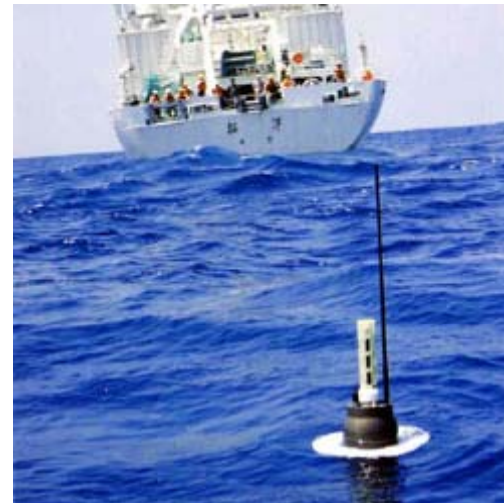
TAO-TRITON Array

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Argo Project

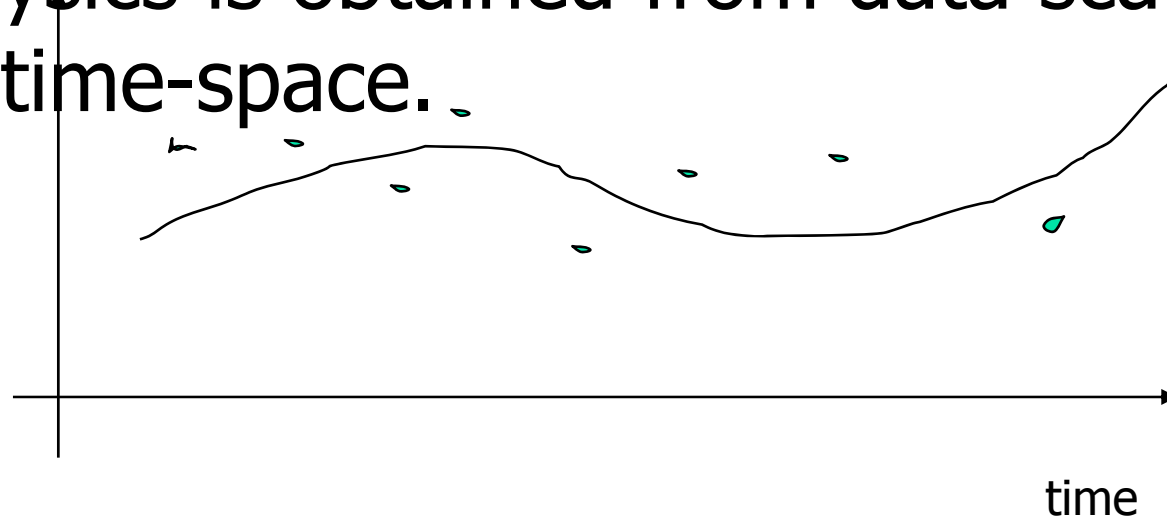
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Methods of Data Analysis

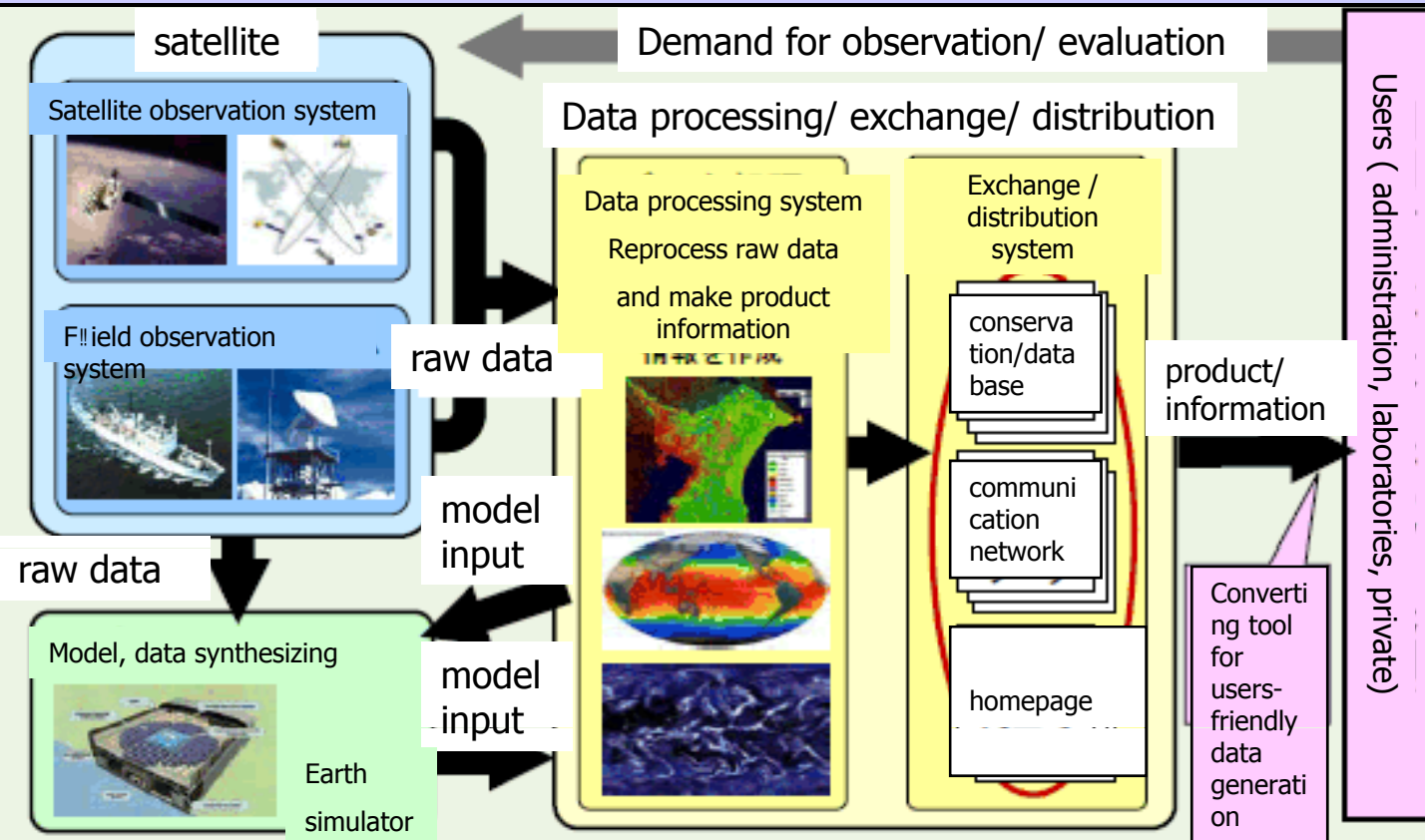
- Four-Dimensional Data Assimilation System (4DDA)
- Analytic value compatible with law of physics is obtained from data scattered in time-space.



GEOSS=Global Earth Observing System of Systems

第1-2-17図 ▶ Construction of Global Earth Observing System (GEOSS) (10-Year project)

- Construction of the Earth observing system by integrating satellite observation and field observation by global cooperation, maintaining former observation systems and complementing their weak points.
- Adjust observations by individual countries and international agencies, and realize effective and efficient Earth observation.
- Observation to meet users' demand (from nine public benefit areas such as climate change, water circulation and natural disasters)



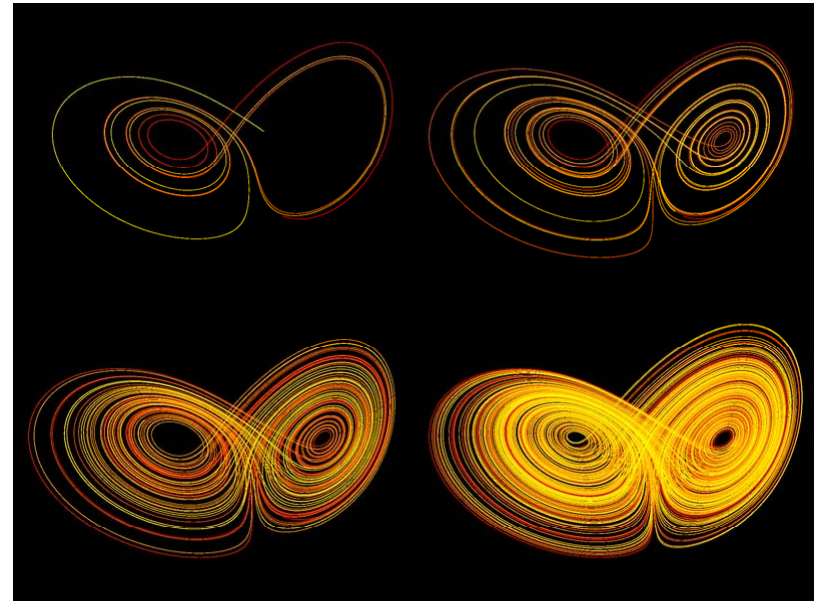


† Source: GROUP ON
EARTH OBSERVATIONS



The Future is not Decided !

- Discovery of chaos !
- Even if mechanism is determinate, behavior and activity are not always determined.



Wikipedia



Summary

- Prediction is essential for 21st Century society !
- Accuracy of prediction has advanced by development of science and technology.
- New ways to use prediction are possible in the information society.
- Prediction is important for making future decisions such as global warming issues !