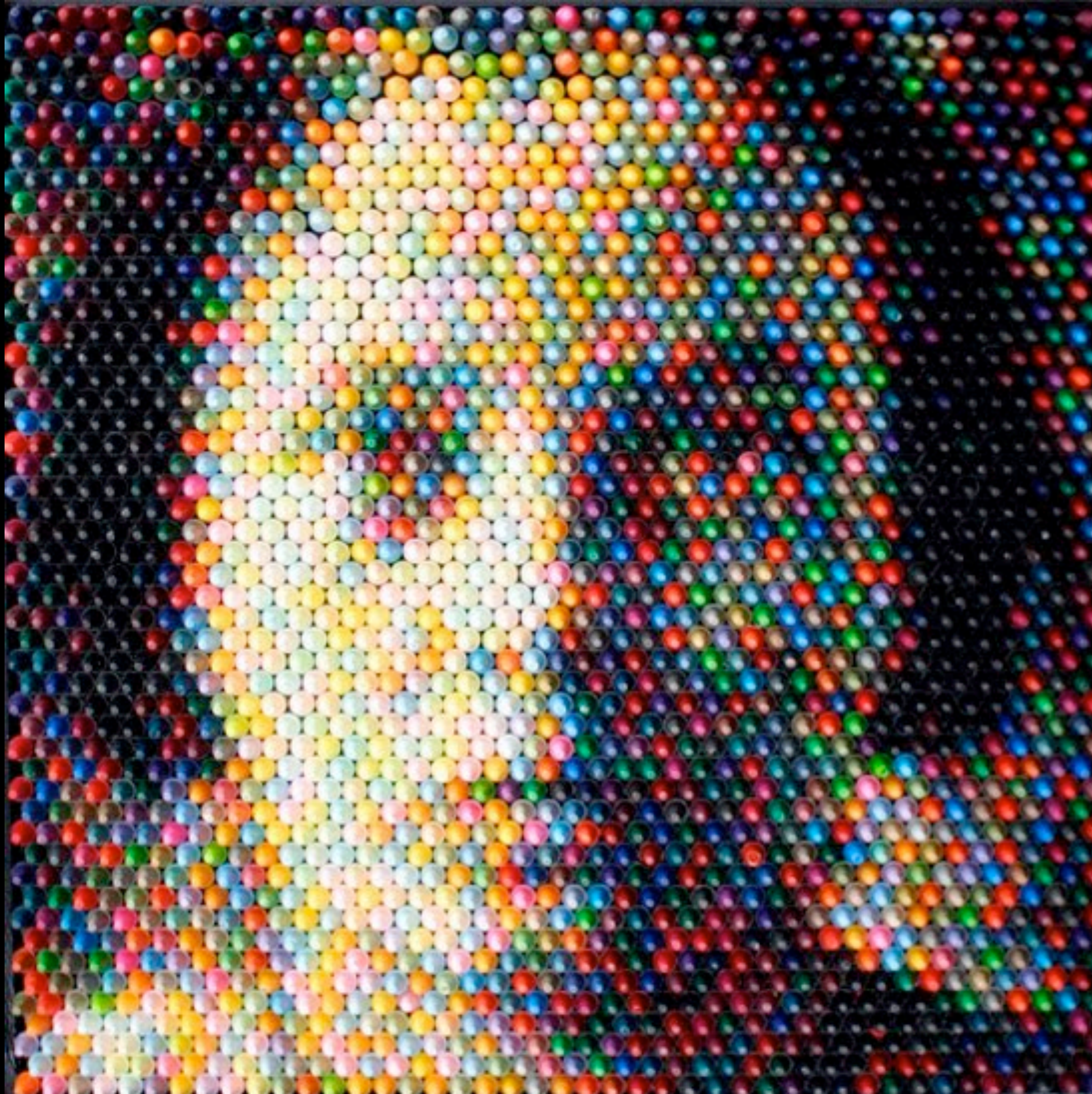
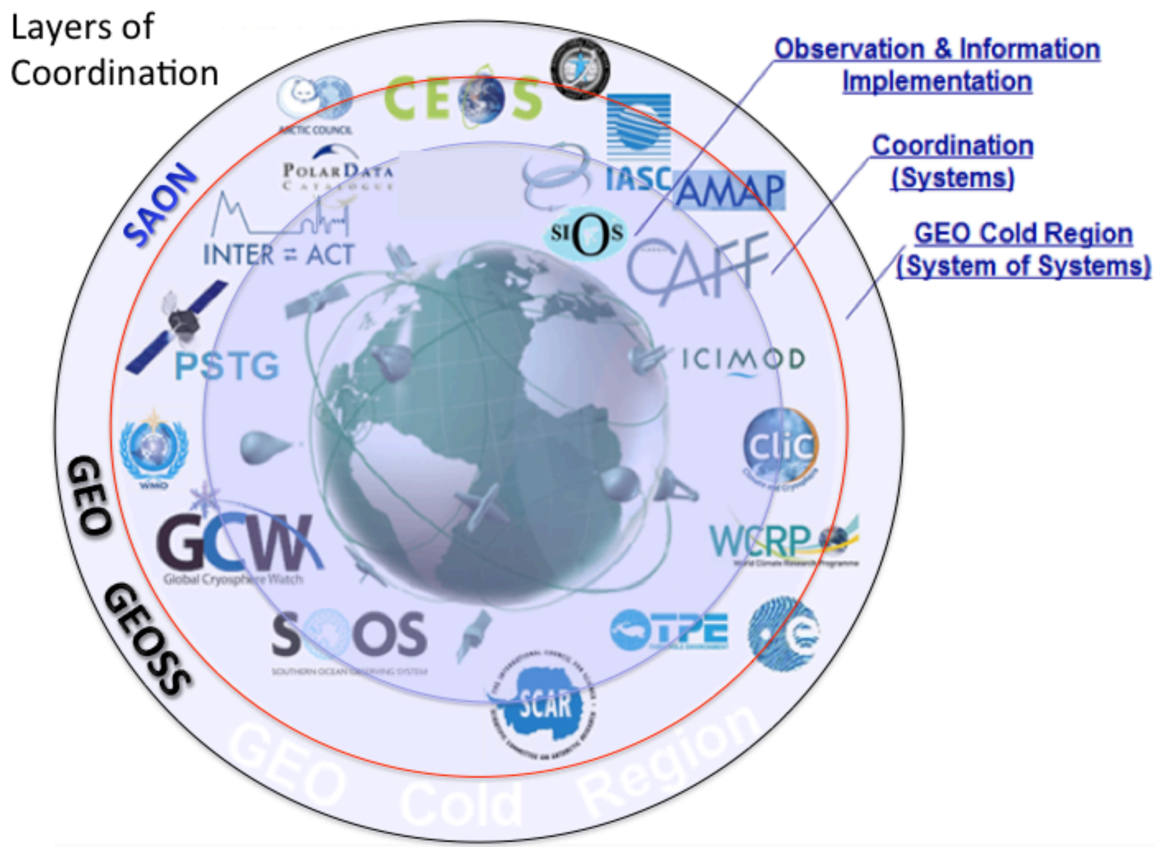
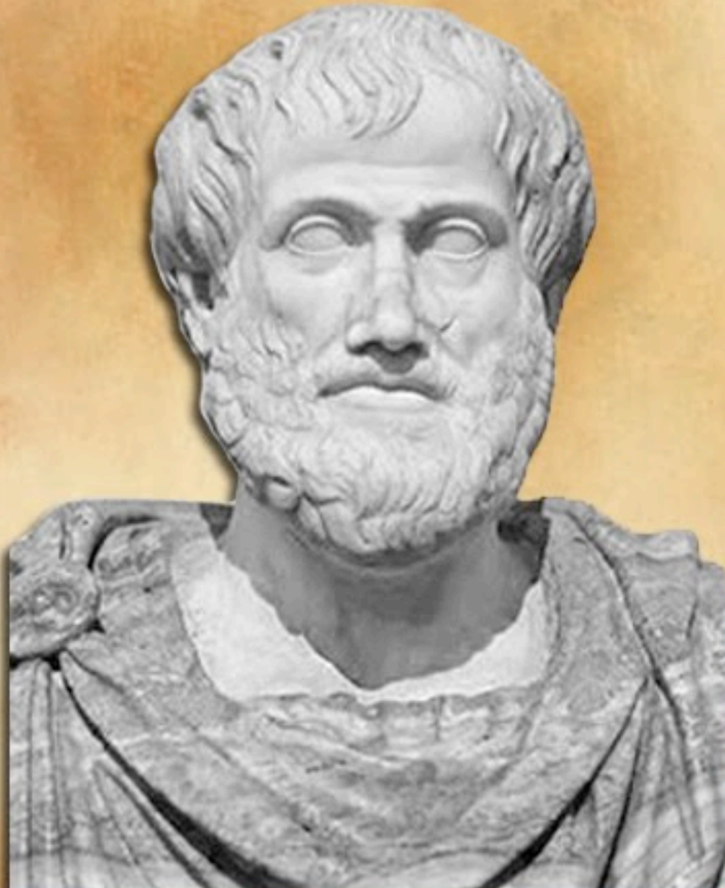
The Sum of the Parts



Thesis: ***The integration and coordination of observing system components can be beneficial, but only to a point.***

Is this too much?





THE WHOLE IS GREATER THAN THE SUM OF THE PARTS

Strong emergence says that systems can have qualities not directly traceable to the system's components, but rather to how those components interact.

Complex systems are systems where the collective behavior of their parts entails *emergence* of properties that can hardly, if at all, be inferred from properties of the parts.

Complex system theory is, well, complex!

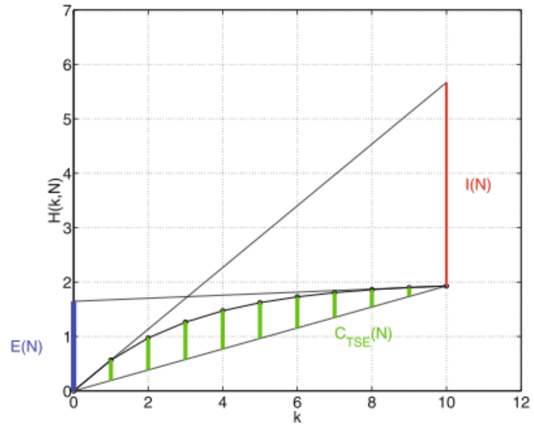


Fig. 1. (Color online) The figure shows schematically for a system with N elements the relationship between the mean entropy of subsystems of size k, $H(k,N)$, the integration $I(N)$ (4), the excess entropy $E(N)$ (6), and the TSE-complexity $C_{TSE}(N)$ (12).

2. The excess entropy of a system consisting of two subsystems A and B is always larger than the mutual information between these two subsystems:

$$E(X_{A\cup B}) \geq I(X_A : X_B).$$

3. The excess entropy of the union of two subsystems is always larger than the excess entropy of one of the subsystems.

$$E(X_{A\cup B}) \geq E(X_A) \qquad E(X_{A\cup B}) \geq E(X_B)$$

4. In general the sum of the excess entropies of the subsystems is neither a lower nor an upper bound for the excess entropy of the whole system.

available states. On the other hand, consciousness is experienced as a unity. Tononi et al. translated this intuition into the requirement that the corresponding systems should have both high entropy and a high integration or multi-information (4) on the system level. In the following we will denote their complexity measure by C_{TSE}, where TSE stands for Tononi-Sporns-Edelman. They defined it as

$$C_{TSE}(X_V) := \sum_{k=1}^{N} \left(\frac{k}{N} I(X_V) - I(k,N) \right), \qquad (9)$$

with the abbreviations $I(N) = I(X_V)$ for the multi-information of the whole system and

$$I(k,N) = \binom{N}{k}^{-1} \sum_{\substack{Y\subseteq V\\ |Y|=k}} I(X_Y)$$

for the average multi-information of subsystems of size k. This complexity is the higher the larger the increase of the integration with the size of the subsystems deviates from a linear one.

One can express C_{TSE} also using the mean entropies of the subsystems of size k or the mean mutual information for bipartitions into subsystems of size k and $N-k$. A particular interesting representation shows its relation to the excess entropy. If we denote the mean excess entropy of all subsystems with k elements by $E(k,N)$ we get for the TSE-complexity

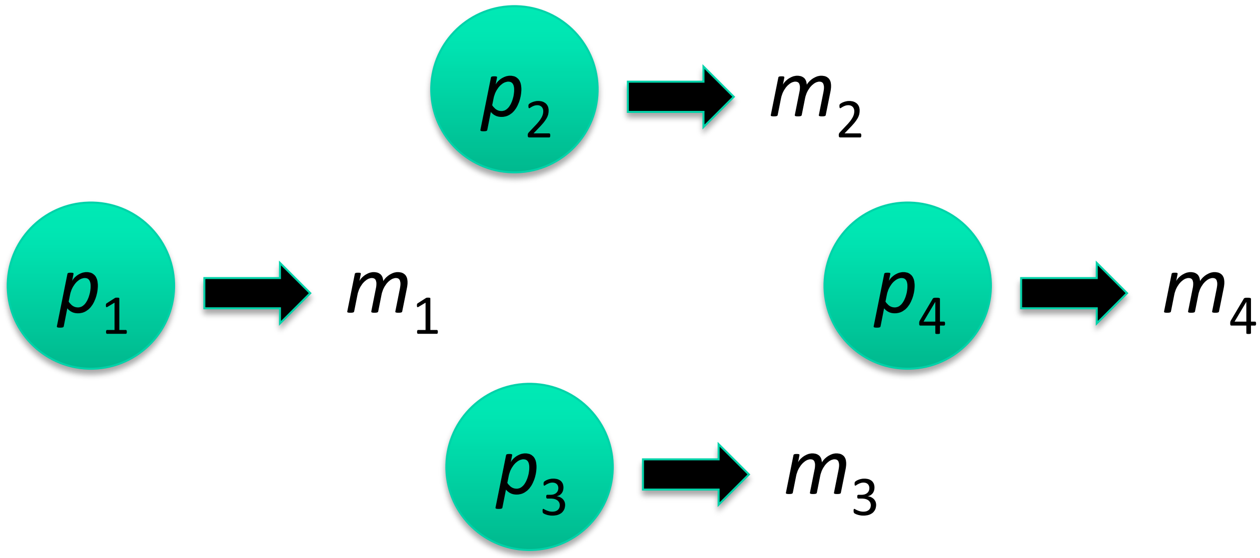
$$C_{TSE}(X_V) = \frac{1}{2} \sum_{k=1}^{N} E(k,N). \qquad (10)$$

For the proof see Appendix B. Using

$$E(k,N) = \frac{1}{\binom{N}{k}} \sum_{Y\subseteq X, |Y|=k} E(X_Y)$$

Let's keep it simple…

The Total Benefit from Independent Parts

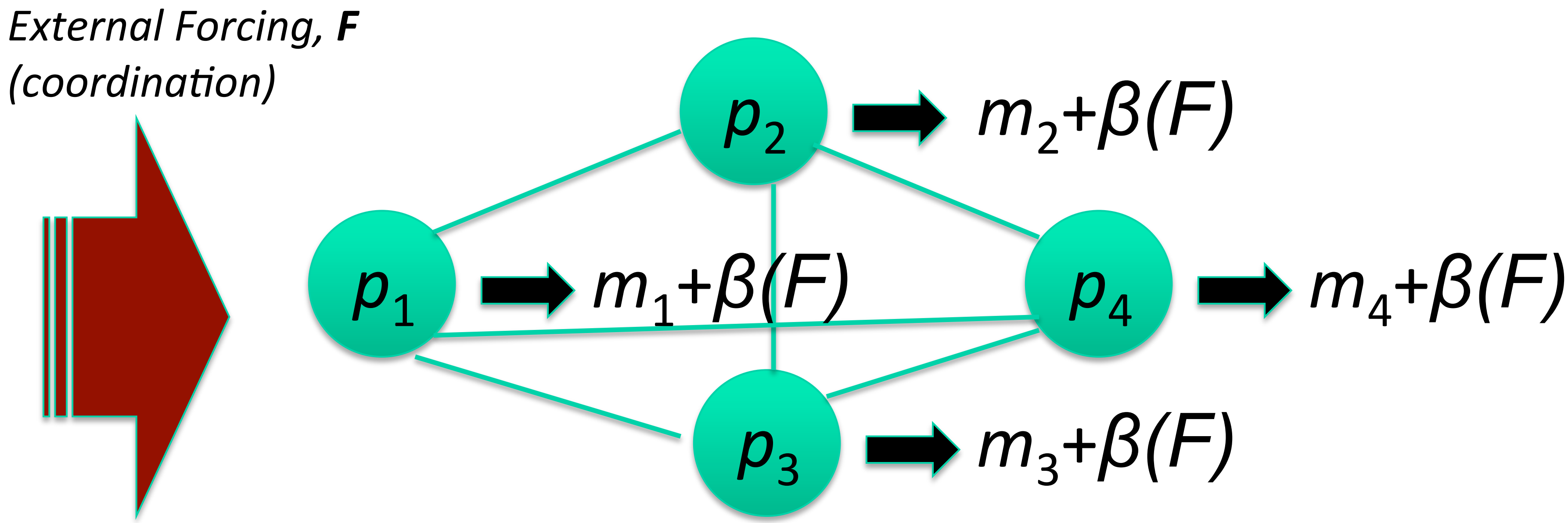


where p_i is a "part", e.g., a surface station, and m_i is a benefit from that part. The total benefit to society (emergence) is:

$$E = \sum_i m_i$$

so that the whole (benefit) is equal to the sum of the parts.

The Total Benefit from an Integrated, Coordinated Network of Parts



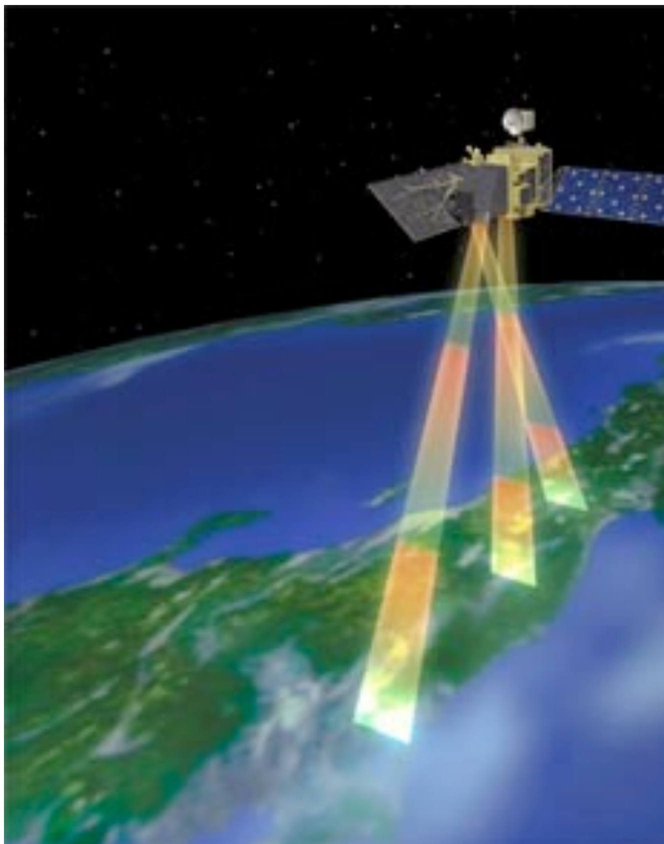
where p_i is a part, m_i is a benefit from that part, and $\beta(F)$ is an added benefit. The total benefit to society (emergence) is:

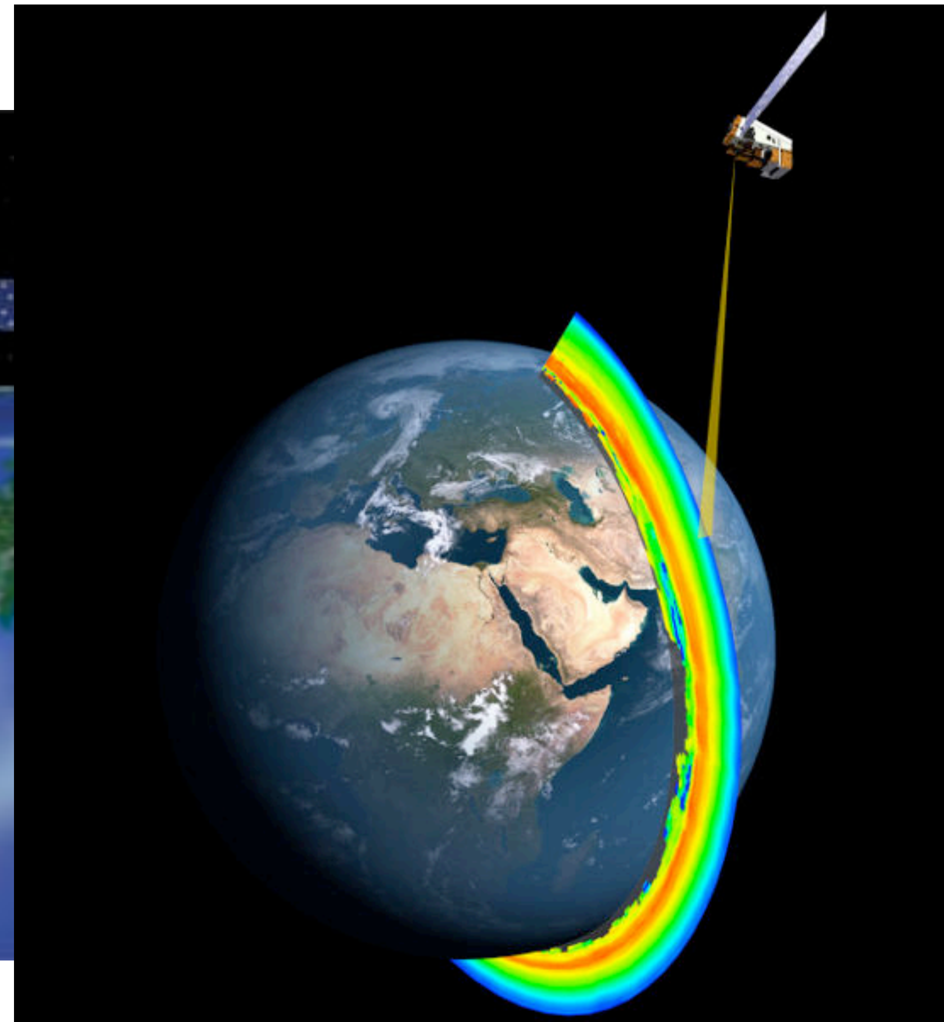
$$E' = \sum_i [m_i + \beta(F)] > \sum_i m_i$$

so that the whole is greater than the sum of the parts.

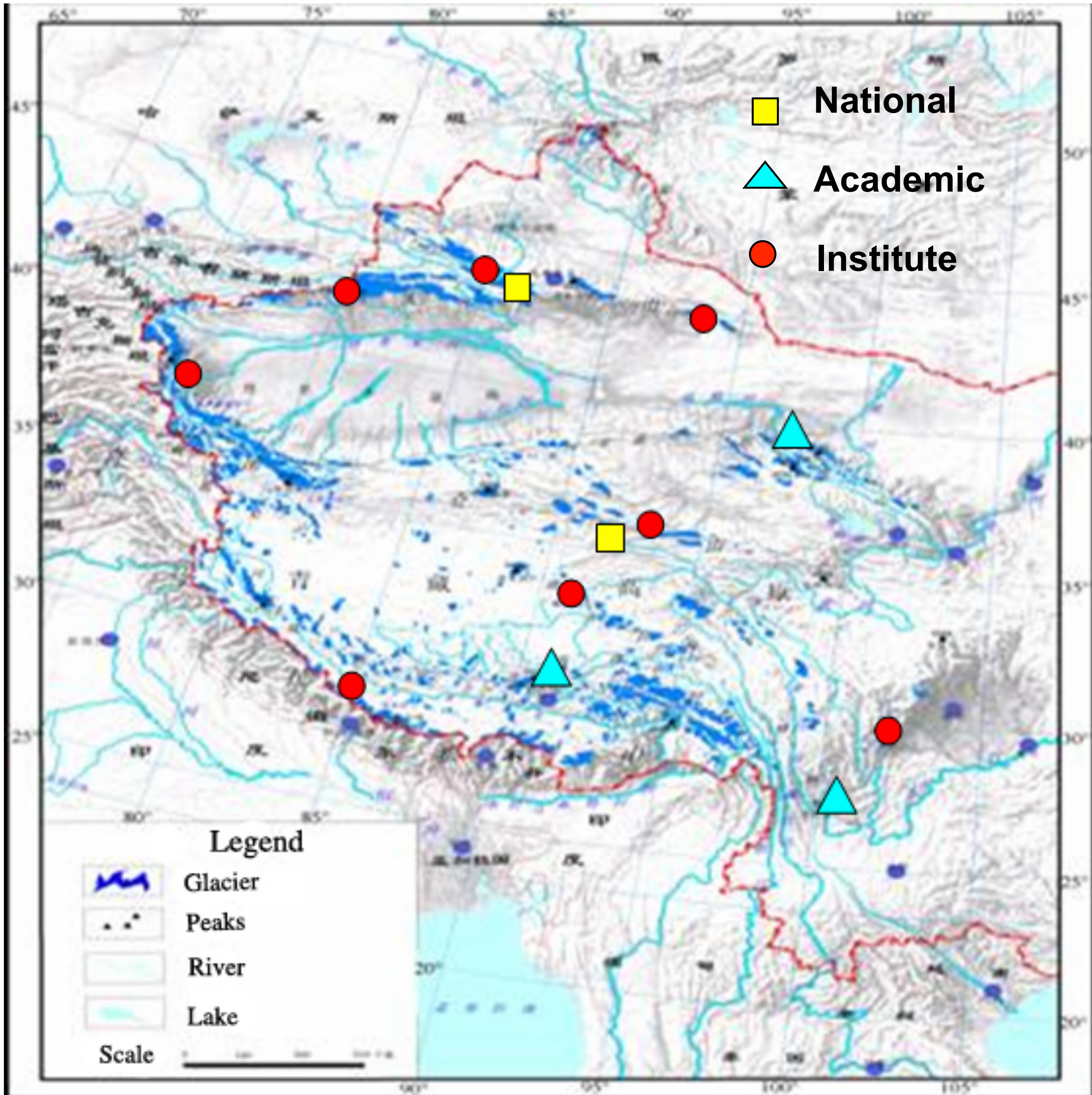
There are many individual in situ measurement sites, some going back many decades. They all operate independently.

Similarly, there are many individual satellites. Most operate <u>independently</u>.





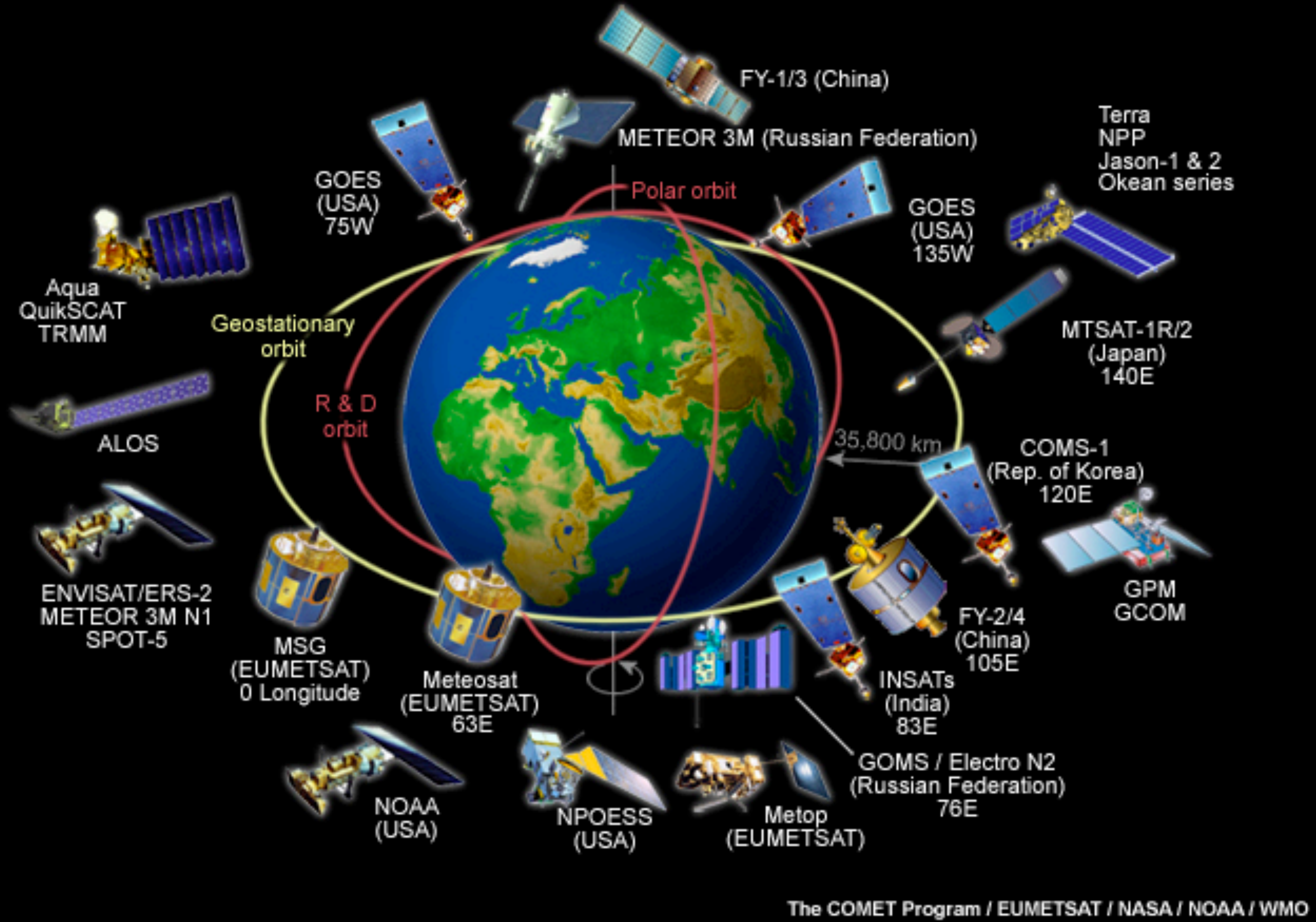
The challenges are varying ownership, operational status, measurement methods, both for in situ…



Cryospheric observation stations in China

- *National supported observation stations：2*
- *Academy-based observation stations：3*
- *Institute-based observation stations：9*

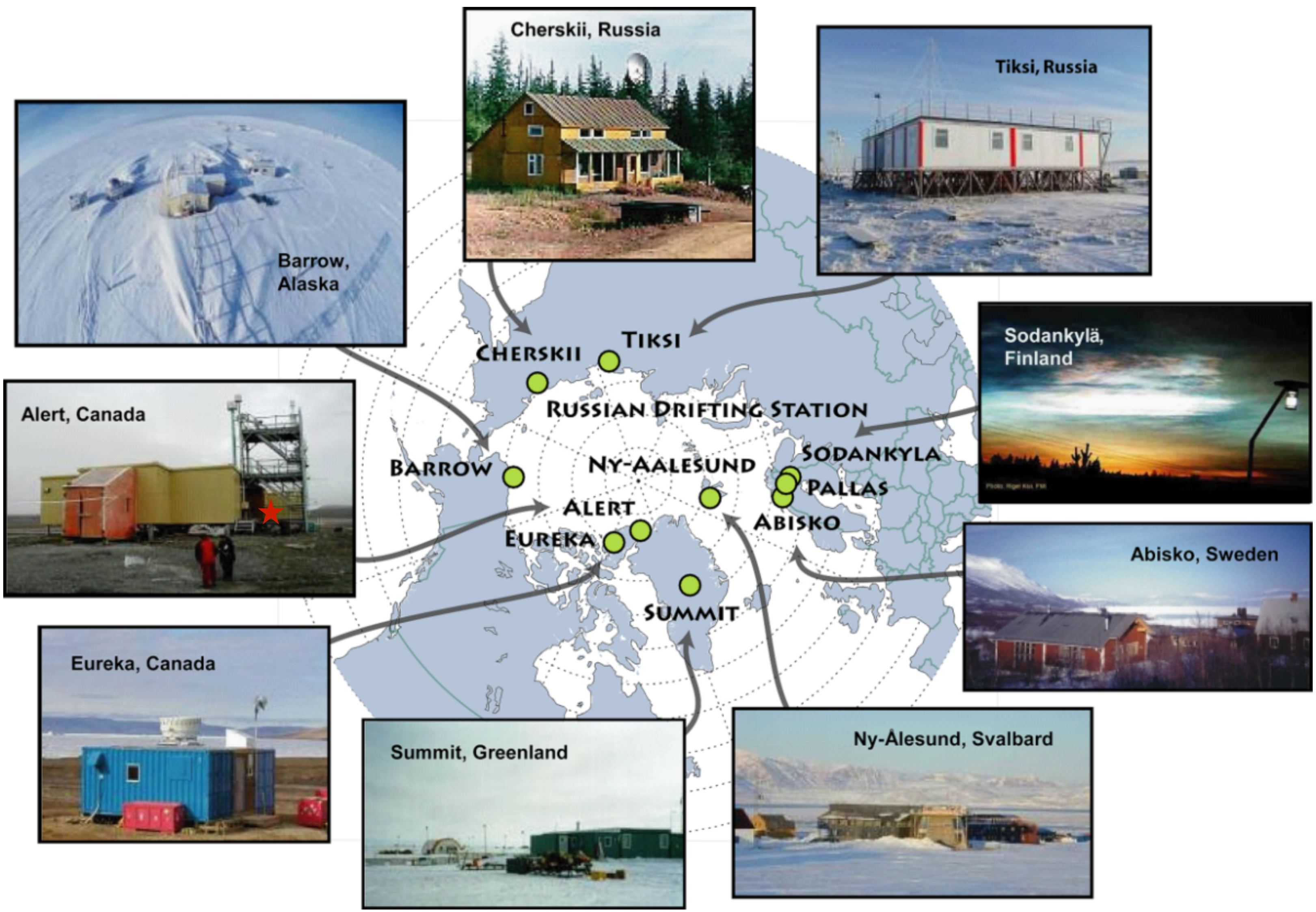
…and satellite systems



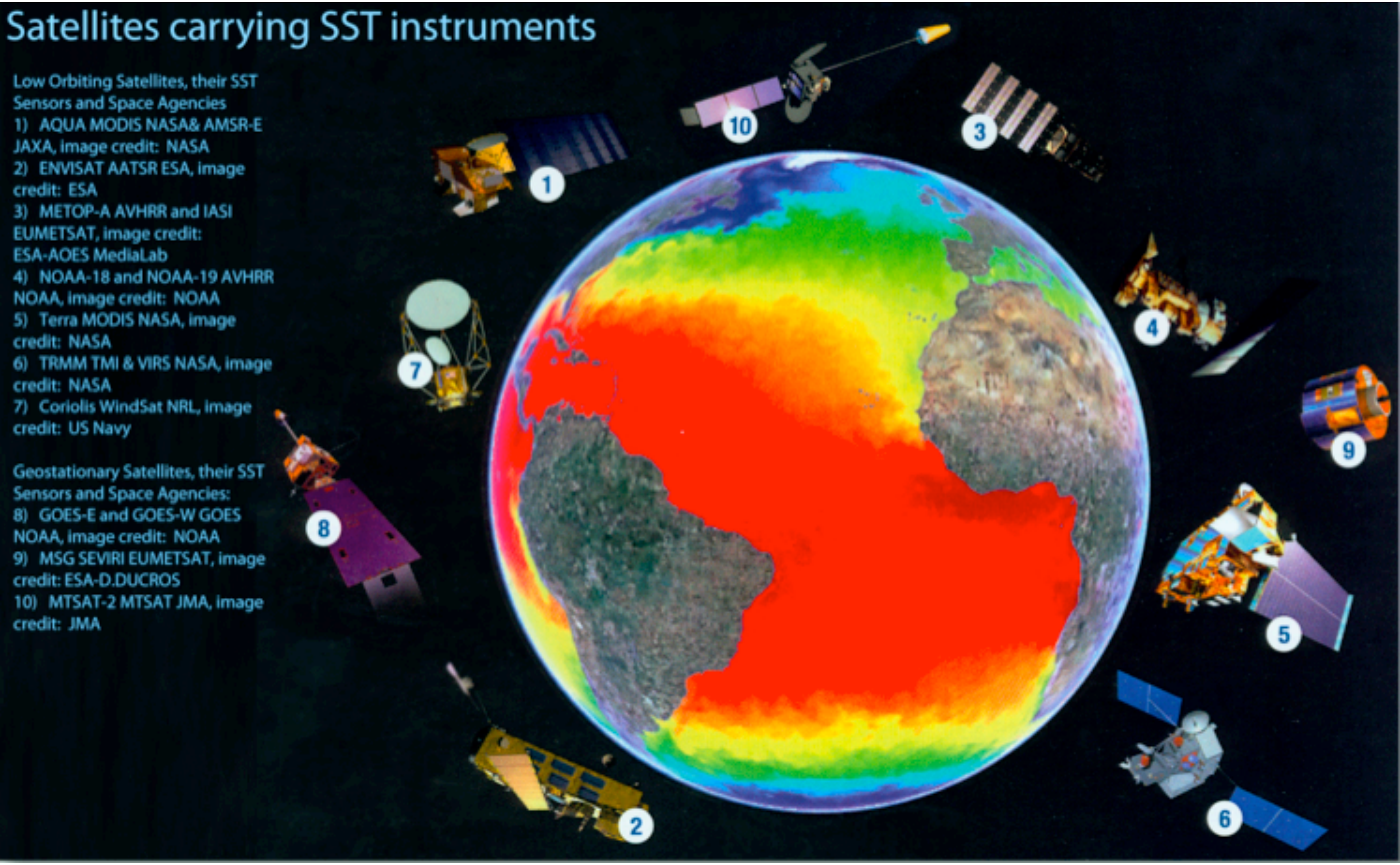
Elements of Integration and Coordination (the "forcing")

- Measurement standards and best practices
- Community assessment of observational requirements
- Community assessment of user requirements
- Quality control and maturity assessments
- Core sets of measurements
- Data standards
- Data distribution interoperability
- Coordination with other observing systems (in situ + satellite)
- Broader participation by countries
- Increased funding opportunities
- Sustainability

Example of basic coordination: International Arctic Systems for Observing the Atmosphere (IASOA)



Example of basic coordination: Virtual Satellite Constellation for Sea Surface Temperature

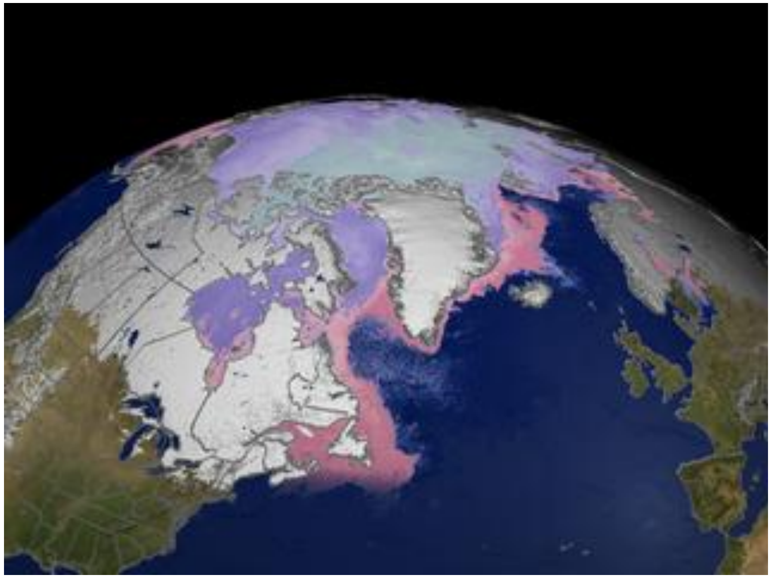


Assessment with the goal of integration: Integrated Global Observing Strategy Partnership

The IGOS themes were developed primarily to assess current observing systems, including capabilities and requirements.

The **IGOS Cryosphere Theme** led to a broader effort…

Global Cryosphere Watch (GCW)



GCW was approved by the World Meteorological Organization Congress in 2011

GCW will provide authoritative, clear, and useable data, information, and analyses on the past, current and future state of the cryosphere to meet the needs of WMO Members and partners in delivering services to users, the media, public, decision and policy makers

GCW coordination element: Measurement standards and practices

WORLD METEOROLOGICAL ORGANIZATION

TECHNICAL REGULATIONS

VOLUME I

General Meteorological Standards

and

Recommended Practices

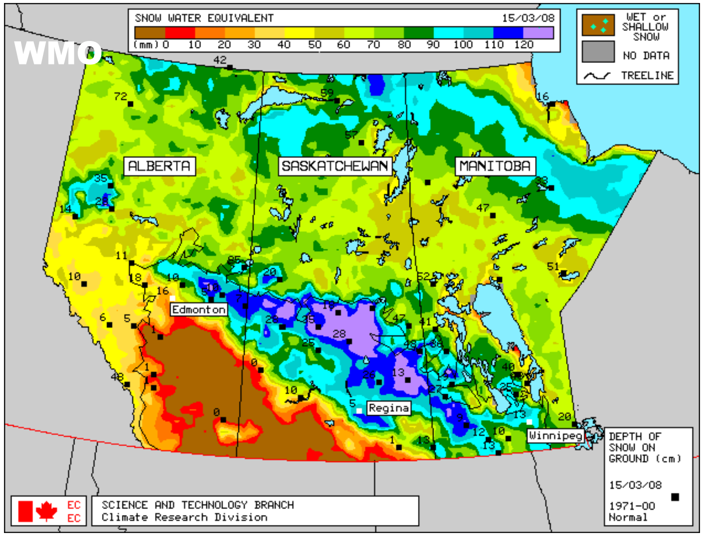
1988 edition

Basic Documents No. 2

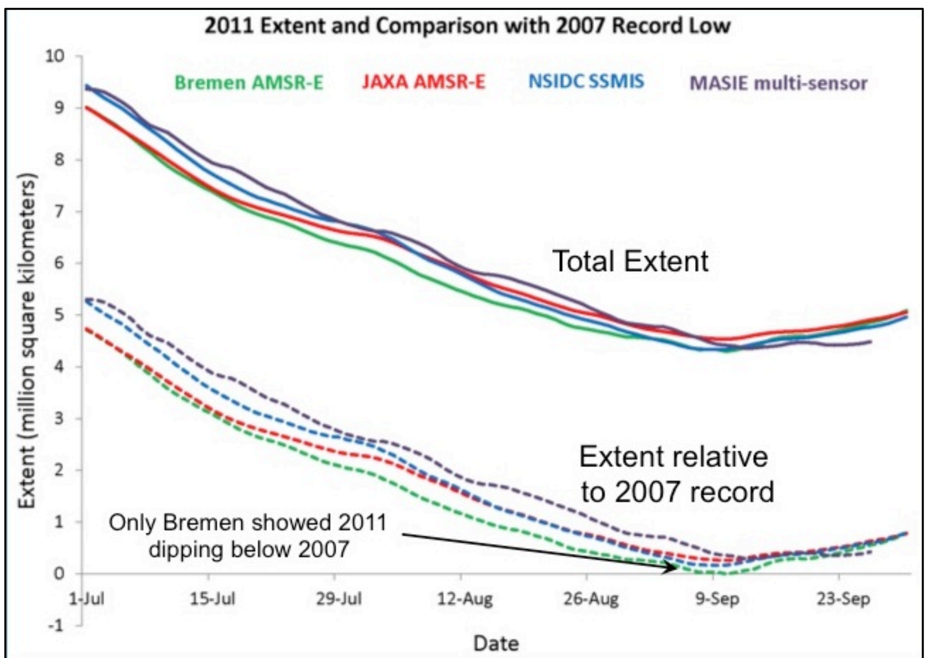
WMO - No. 49

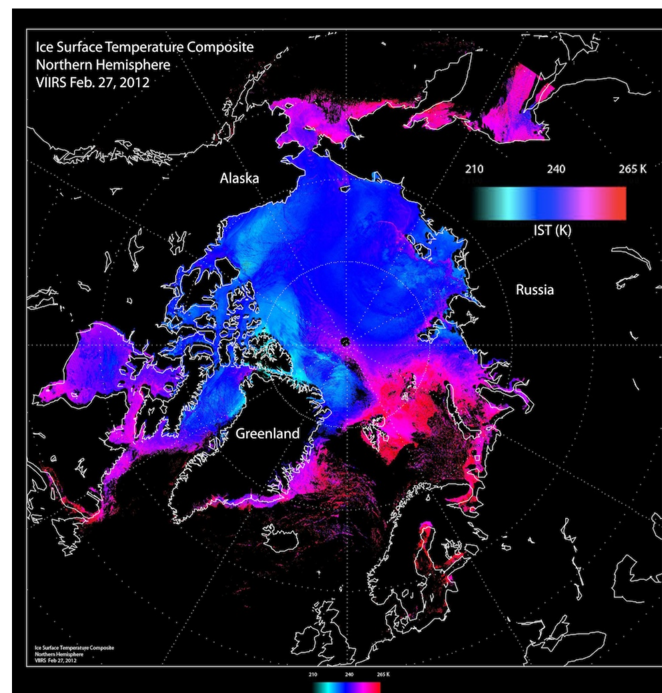
Secretariat of the World Meteorological Organization – Geneva – Switzerland
1988

GCW coordination element: Authoritative Products

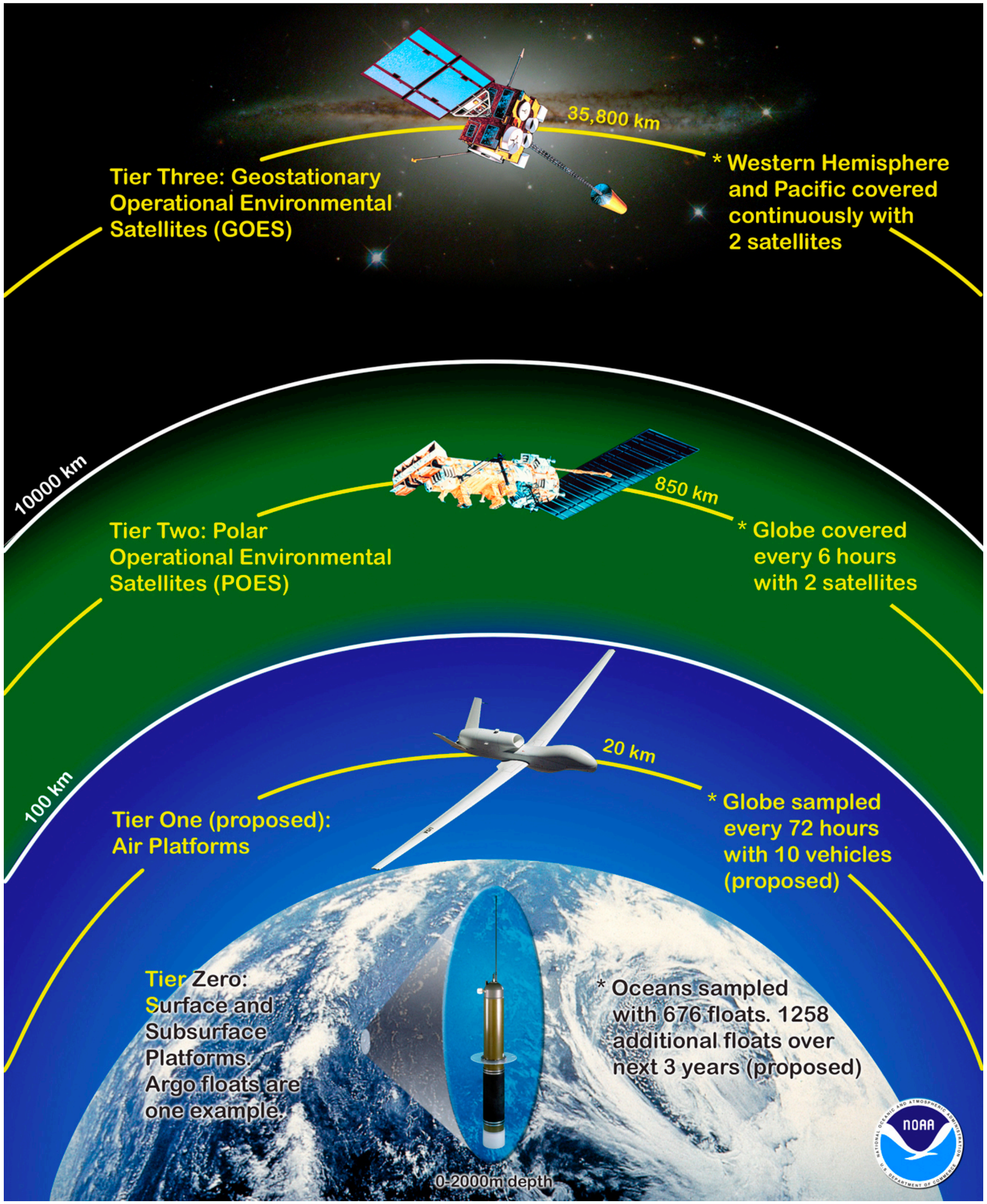


- Routine evaluation of products
- Product intercomparisons
- Self-assessements of maturity, etc.
- Products meet user needs
- Sustainable product development and production
- Transfer from research to operations



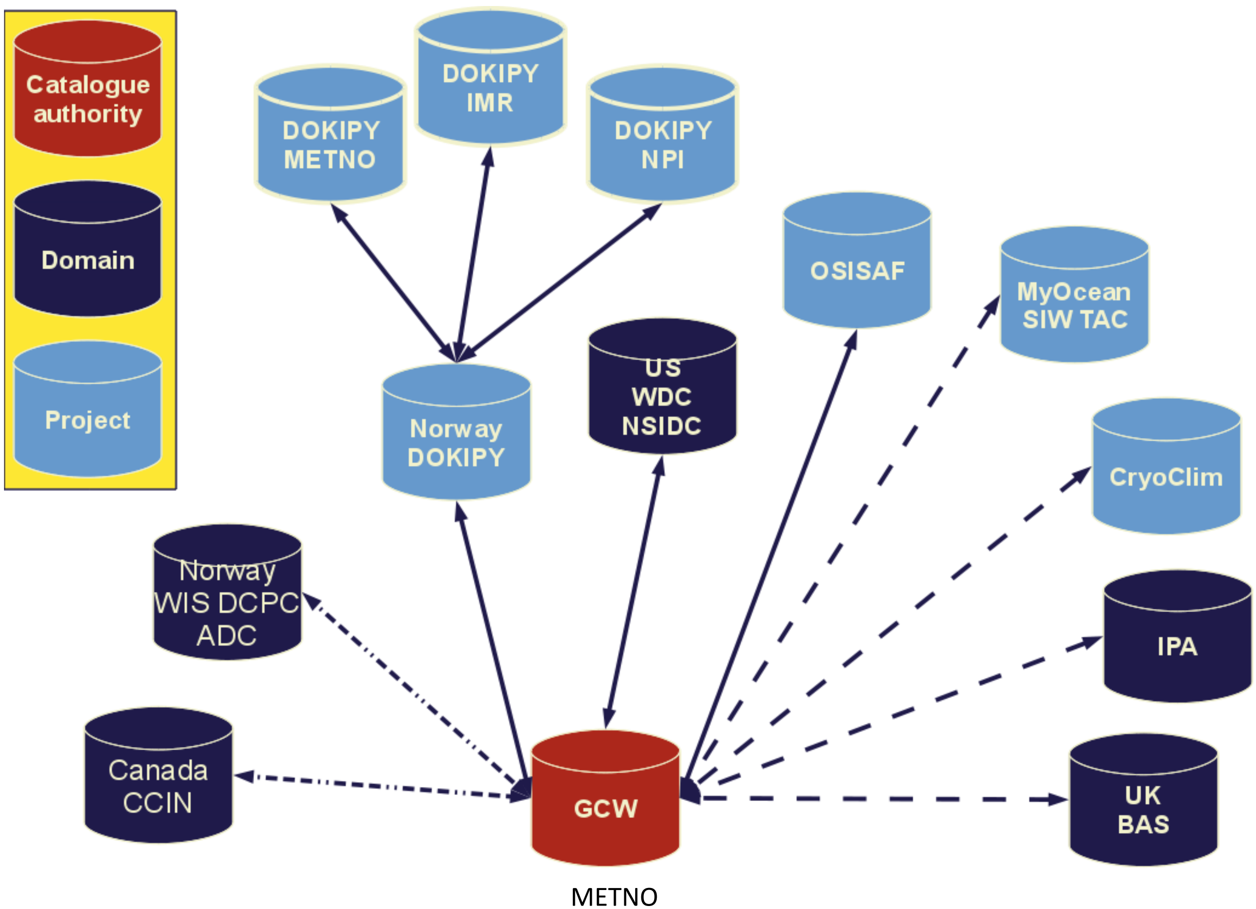


GCW coordination element: Integration across observing systems



GCW coordination element: Data Interoperability

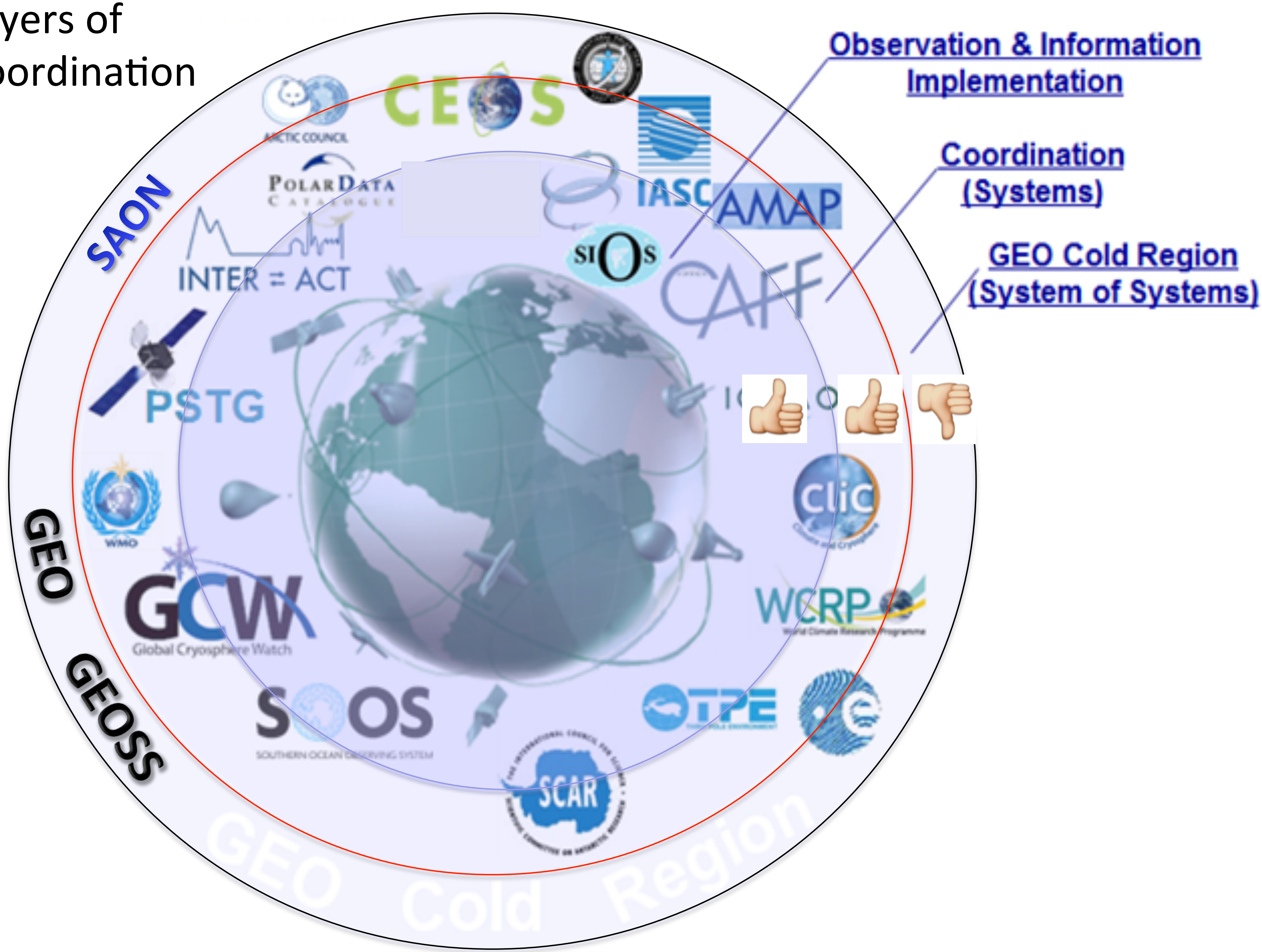
The GCW web portal will provide the ability to exchange cryosphere data, metadata, information and analyses among a distributed network of providers and users in support of informed decision-making.



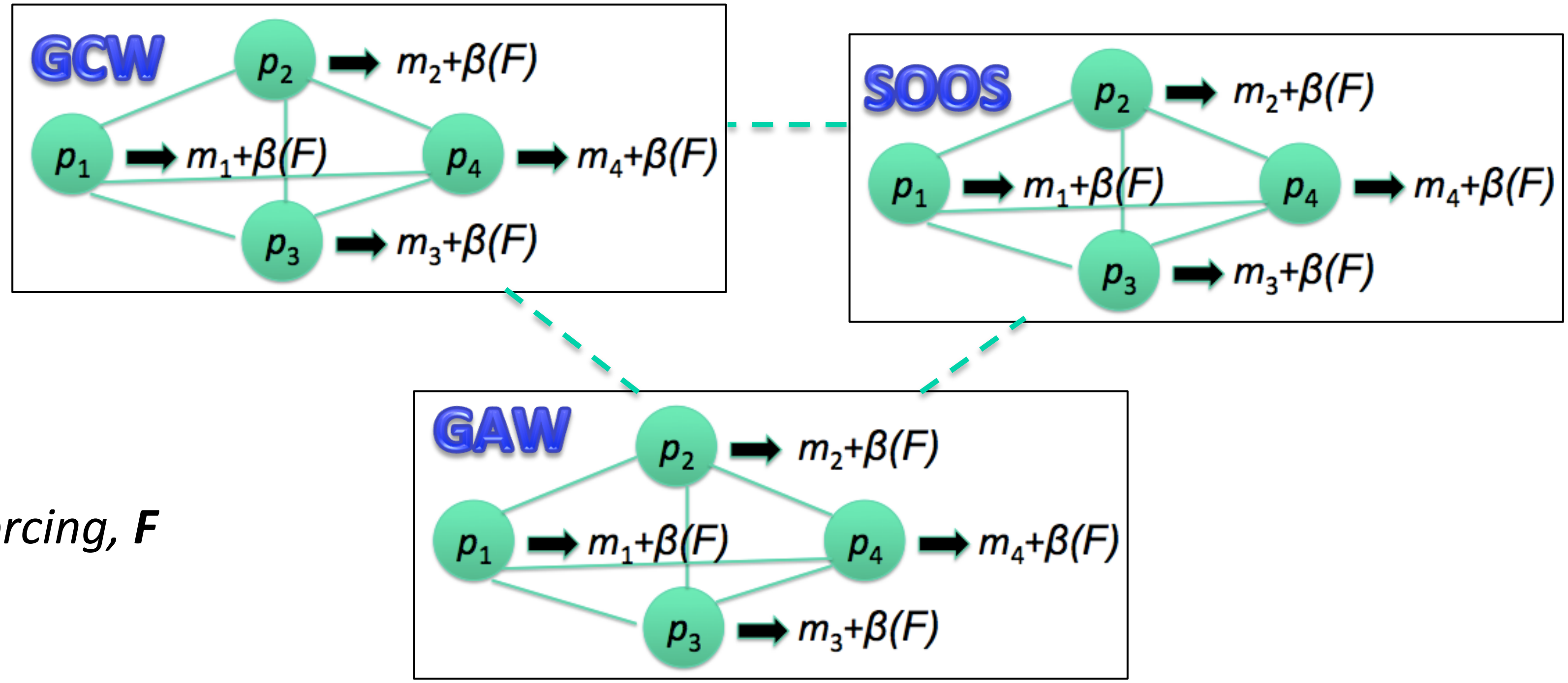
GCW coordination element: information integration and distribution

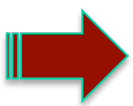
globalcryospherewatch.org

Layers of Coordination



The Total Benefit from a System of Systems





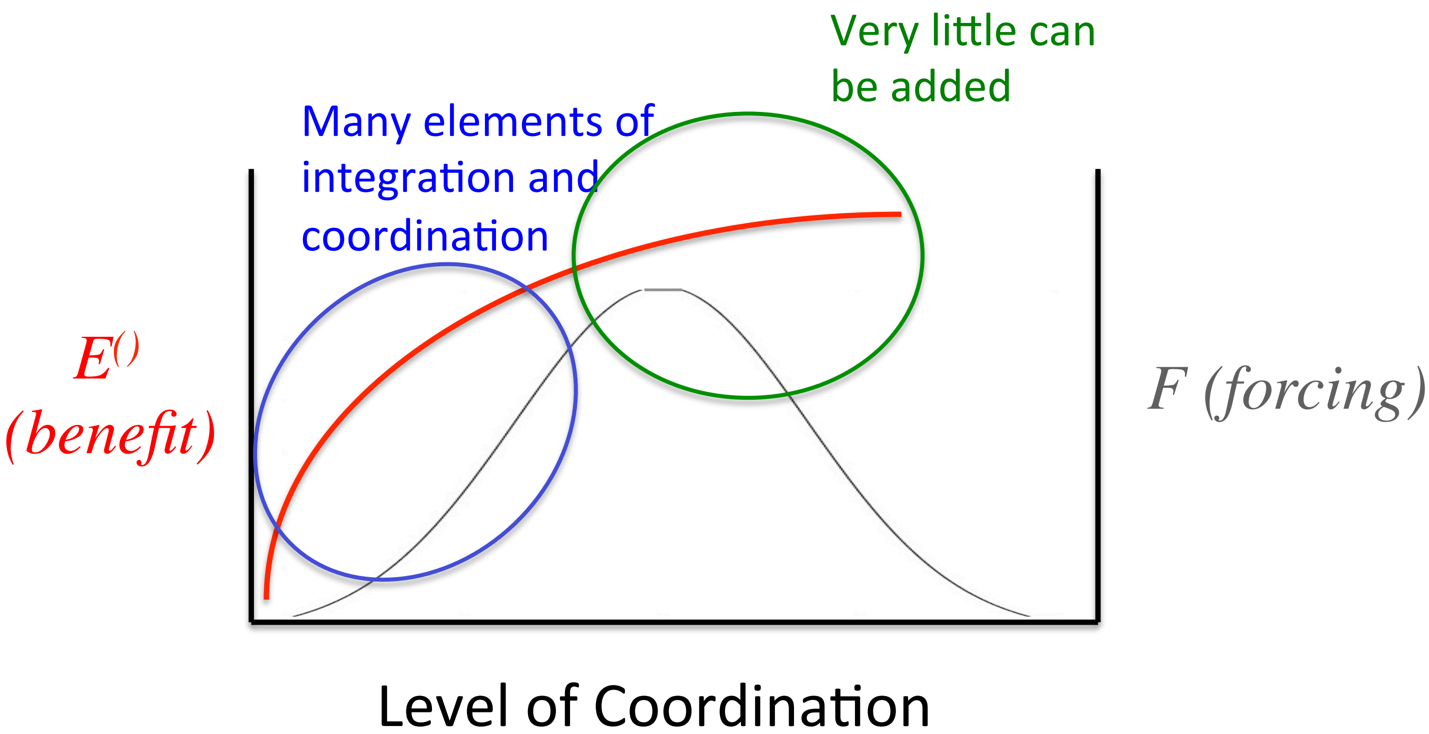
External Forcing, ***F***
(smaller)

At this level, the external forcing and hence the added benefit is **smaller**. The total benefit to society is:

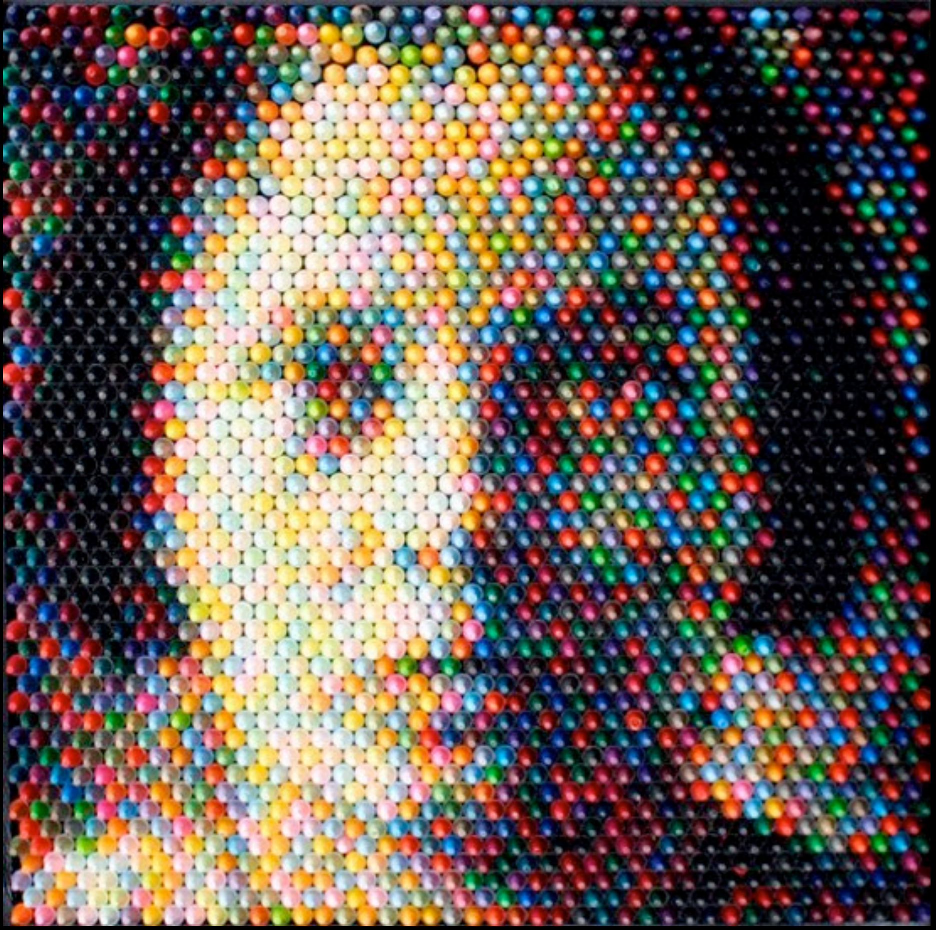
$$E'' = \sum_{n} \sum_{i} [m_i + \beta(F)] \not\gg E'$$

so that the whole <u>is not significantly greater than</u> the sum of the parts.

Benefit and Forcing vs Level of Coordination

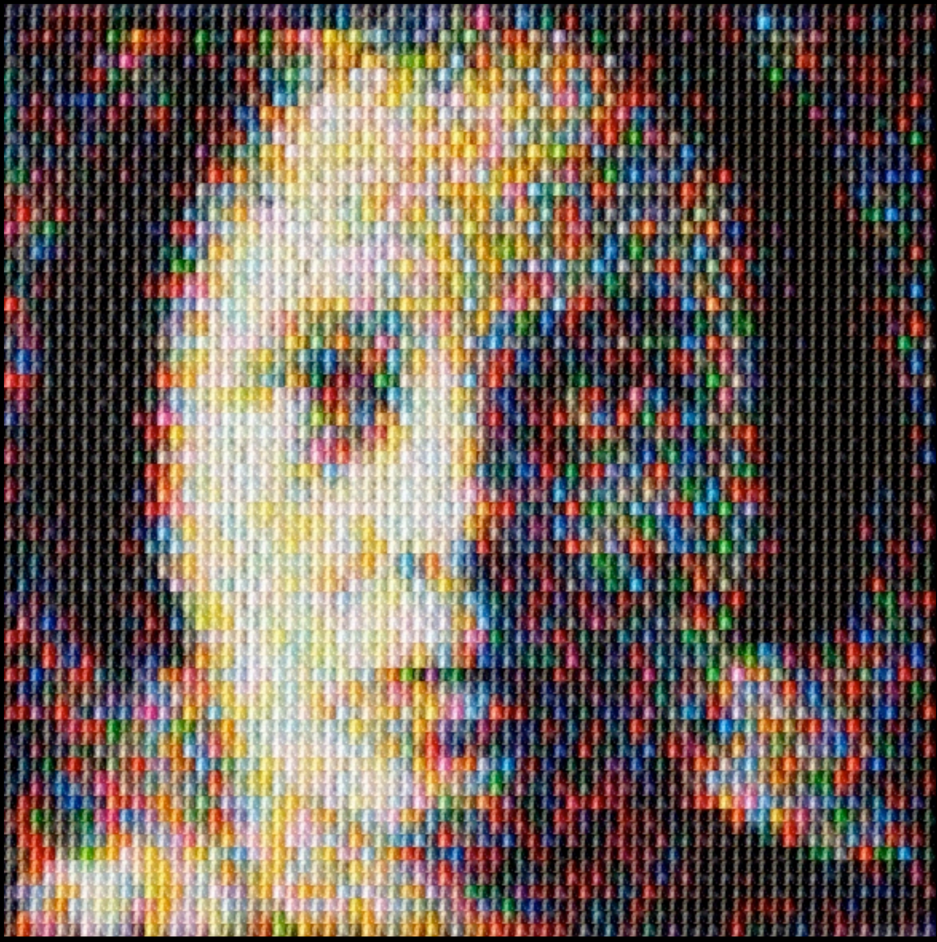


Note: This above is a qualitative assessment based on experience, not quantitative evidence.



The whole <u>is</u> greater than the sum of the parts.

But it is not necessarily greater than the sum of the sums of the parts.



This picture is made up of 1,000s of versions of the picture at upper left.

GCW
Global Cryosphere Watch