# 地球観測の科学的要請とミッション構築について

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# Outline

- いくつかの例から

1. Tropical Rainfall Measuring Mission : Legacy

2. Global Precipitation Measurement : Current

3. ACCP: Ongoing

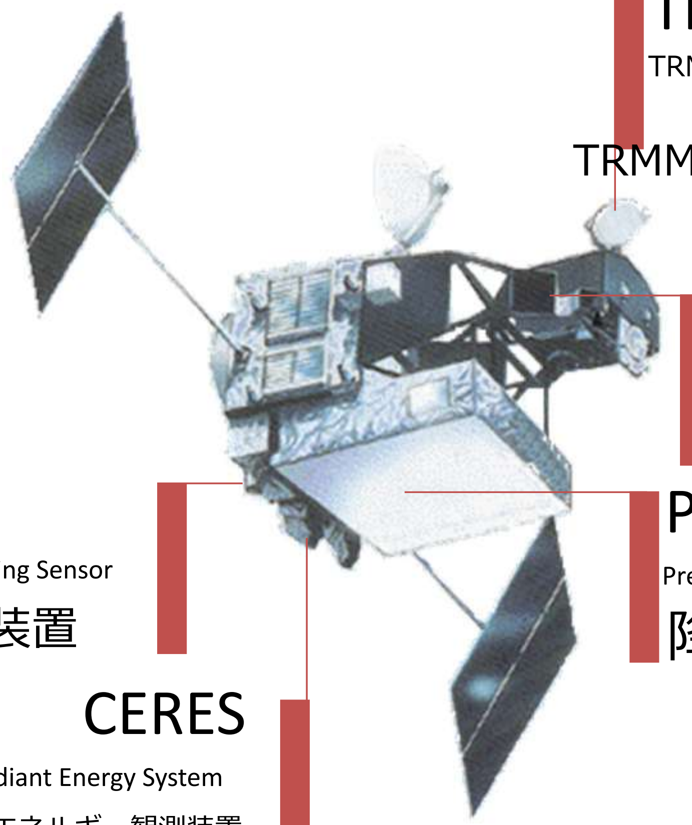
- 日本の地球衛星観測の在り方についての議論

Tropical Rainfall Measuring Mission
Global Precipitation Measurements

# TRMM & GPM

# Tropical Rainfall Measuring Mission

1997.11.28-2015.4.8



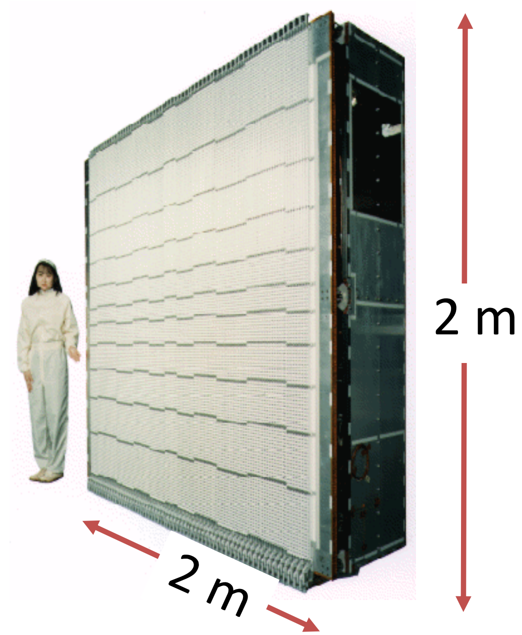
**TMI**
TRMM Microwave Imager
TRMMマイクロ波観測装置

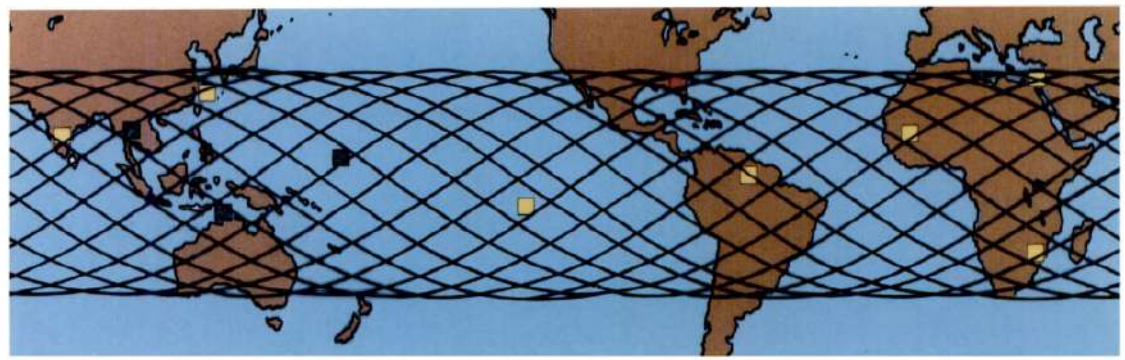
**VIRS**
Visible Infrared Scanner
可視赤外観測装置

**LIS**
Lightning Imaging Sensor
雷観測装置

**PR**
Precipitation Radar
降雨レーダ

**CERES**
Clouds and Earth's Radiant Energy System
雲および地球放射エネルギー観測装置



# Tropical Rainfall Measuring Mission
# 畚野信義博士　「衛星余話」

数多くあるTRMMの「初」の中で、私が最も重要であり、値打ちが有ると思っているのは、宇宙科学研究所のミッションを除けば、TRMMは「研究者が提案し、実現した（実現させた）」我が国では初めての衛星計画であるということである。私はこの機会に、二十年余に渉るその歴史の中で、特にその初期の時代における手探りの努力の幾つかを紹介しておきたい。アメリカでは研究者が自分達の研究に必要なデータを得るために、新しい衛星計画を提案し、自分達で様々な努力をして実現させて行く。我が国でも研究者が意見や希望を述べる機会が作られて来つつある。しかし研究者の本質はまだまだ受け身であり、お上（科学技術庁、宇宙開発事業団など）が研究者の知恵を吸い上げ、都合の良いものだけを拾って計画を作り上げるための舞台の上で踊っているに過ぎないような気がする。我が国でも自分の研究は始めから終わりまで、自分たち自身の力と責任でやるというシステムとカルチャーを、若い研究者の人たちが築いて行くことを期待している。

経過抜粋（高薮）:　電波研究所（現情報通信研究機構）は1970年代半ばから宇宙からの地球観測に3次元降雨観測を考える。1978年航空機搭載2周波雨域散乱計・放射計の開発。1983年NASAから共同研究打診。1985年開始。1986年宇宙分野最高レベル会議で日米承認。1988年Report of the Science Steering Group発出。1992年リオ地球サミット（環境と開発に関する国連会議）が追い風となる。1997年11月28日打ち上げ。


# TOGA計画とのリンク

TRMM is being planned in close conjunction with the ongoing (1985-1995) international Tropical Ocean and Global Atmosphere (TOGA) program, which is designed to improve our understanding of ocean-atmosphere interaction and to develop coupled models for long-range forecasting and climate prediction.

TOGA: マルチスケールの熱帯海洋-大気相互作用の理解を通して月~年の気候予報を目指したWCRPプログラム

# TRMM Goals

- advance the Earth system science objective of understanding the global energy and water cycle by means of providing distributions of rainfall and inferred heating over the globe,

全球水・エネルギー循環の理解

- understand the mechanisms through which tropical rainfall and its variability influence global circulation and to improve our ability to model these processes in order to predict global circulation and rainfall variability at monthly and longer time scales, and

熱帯降水とその変動が全球大循環に及ぼす効果のメカニズム理解

- evaluate a space-based system for rainfall measurement.

衛星降水観測システムの評価

A secondary goal closely connected to the main goals is to better model and understand convectively driven precipitating cloud systems in the tropics, their organization on the mesoscale, and their interactions with the ocean and the ambient atmosphere.

熱帯降水雲システムの理解

## Table 6. TRMM Priority Science Questions

1) What is the four-dimensional structure of latent heating in the tropical atmosphere? How does it vary diurnally, intraseasonally, seasonally, and annually?

大気の４次元潜熱加熱

2) What is the role of latent heat released in the tropics in both tropical and extra-tropical circulations?

熱帯大気の潜熱加熱の熱帯・中緯度循環への役割

3) What is the monthly average rainfall over tropical ocean areas of about $10^5$ $km^2$ and how does this rain and its variability affect the structure and circulation of the tropical oceans?

熱帯海上の10$^5$ｋｍ$^2$（約５度格子）の月平均降水量　→熱帯海洋への効果

4) What is the relationship between precipitation and changes in the boundary conditions at the Earth's surface (e.g., SST's, soil properties, vegetation)?

地表面状態と降水との関係

5) What is the diurnal cycle of tropical rainfall and how does it vary in space?

日変化

6) What are the relative contributions of convective and stratiform precipitation and how does their ratio vary in different parts of the tropics and in different seasons?

対流雨・層状雨の割合

7) How can improved documentation of rainfall improve understanding of the hydrological cycle in the tropics?

雨についての把握の改善→熱帯の水循環の理解の改善

## Table 8. Remote Sensing Science Goals

1) Development, test, and validation of improved rain retrieval algorithms from space
衛星観測による降雨推定アルゴリズムの開発・テスト・検証

2) Tests of and improved methods for rain estimation from geosynchronous satellites—past, present, and future
静止衛星からの降雨推定の改良

3) Further development of multi-data source analysis techniques, blending several types of space and *in situ* sources with different coverage of cloud systems
複数衛星観測を用いた解析手法開発

4) Use of improved knowledge and models of internal precipitating cloud structure to relate to radiative signals received in different microwave channels (active and passive)
降水雲構造とマイクロ波の複数周波数信号との関係

5) Parameterization of diurnal cycle for potential future sun-synchronous measurement opportunities
日変化のパラメタリゼーション

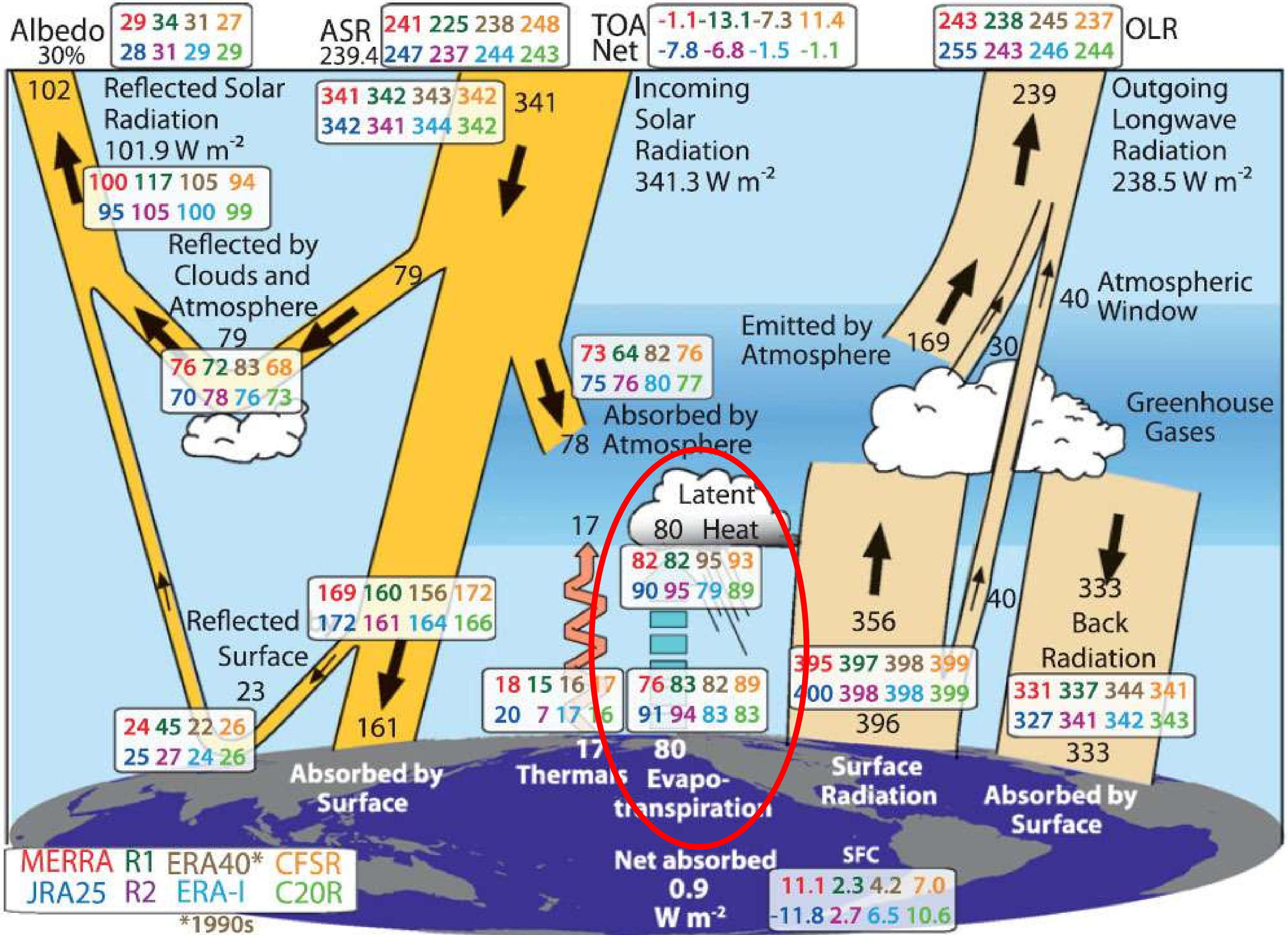
6) Better precipitation statistics for planning future spaceborne precipitation measurement systems
将来の降水観測のための降水統計の改良

7) Use of mission-obtained improved knowledge of convective/stratiform rain ratio to improve sampling techniques for future space missions
対流雨・層状雨の比率の知見

8) Use of mission- and otherwise-obtained improved knowledge of ice phase structure and variability in raining cloud systems to design improved instrument complement for future space missions
固体降水の構造と変化の知見

9) Improved ways to achieve large dynamic range for spaceborne rain radar, which still stays within achievable power, good resolution for passive microw
降雨レーダーのダイナミックレンジの拡大

# Uncertainties in Global Energy Flow Estimates




降水は大気のエネルギー収支の一翼を担う

Trenberth et al. 2011

# Science Questions

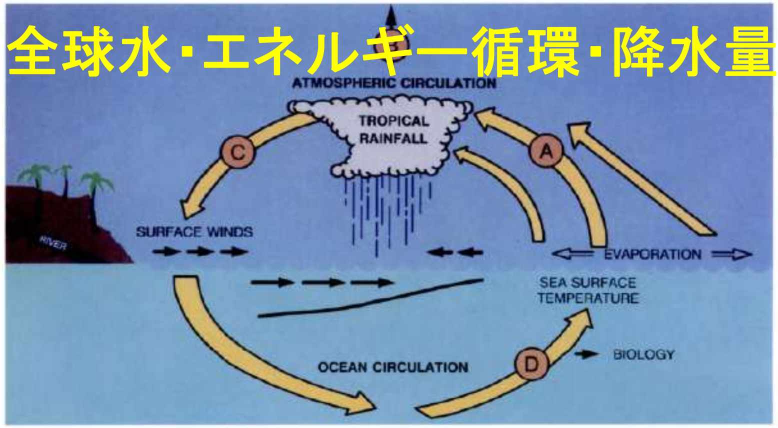
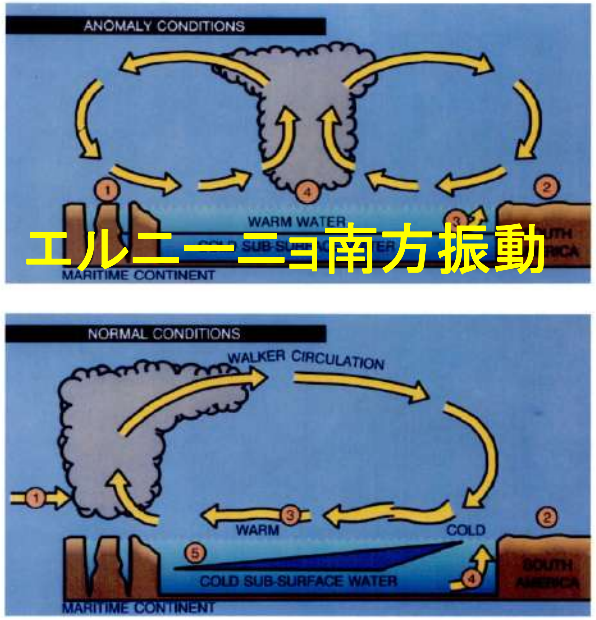
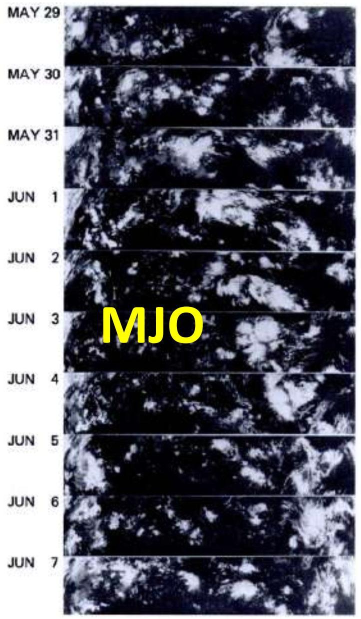



Figure 2. Schematic diagram showing the key role of tropical rain systems in ocean-atmosphere and



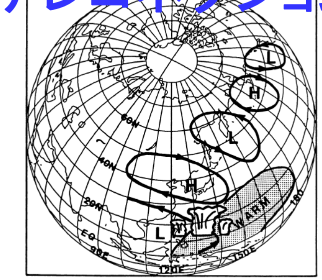




Figure 19. A newly discovered teleconnection characteristic of anti-El Niño years. Schematic pictures show the relationships between SST anomalies, convective activities and atmospheric Rossby wave trains. During summers corresponding to anti-El Niño years in which SST in the tropical western Pacific is warmer than normal, intense convection regions are shifted northward by about 5° to 10° latitude from the normal position south of the Philippines. Atmospheric Rossby waves respond to this tropical heating and propagate downstream over the North Pacific to North America. As a result of the Rossby wave response, east Asian regions including continental China and Japan are covered by anticyclonic circulations, resulting in extremely hot days (Nitta, 1987).

日変化

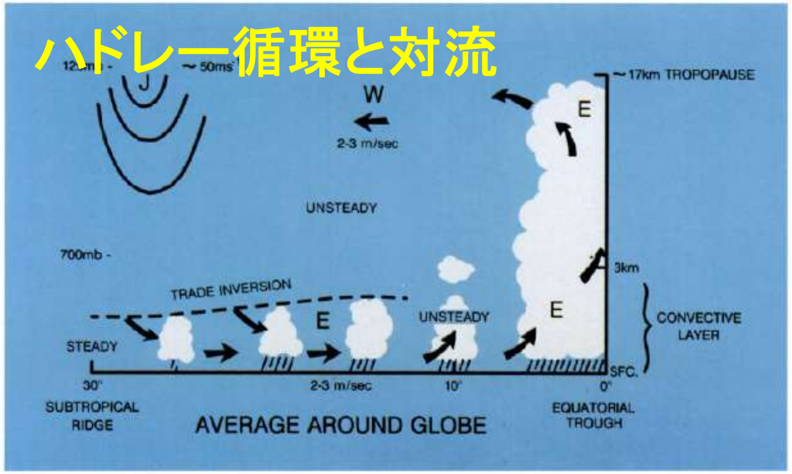



Figure 8a. Schematic illustration of the meridional Hadley circulation, averaged over longitude. The latitude coordinates are located relative to the equatorial trough, specified as 0 degrees and the subtropical ridge line, specified as 30 degrees. The thick arrows denote the mean circulation, with subsidence in the equatorward-flowing trades and rising motion in the equatorial trough, which is concentrated

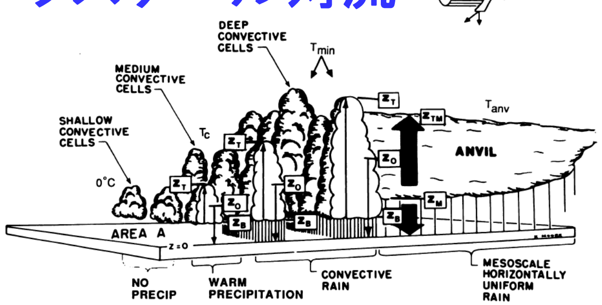



Figure 11. Schematic diagram of a tropical oceanic convective cloud cluster (after Houze and Betts, 1981) showing the younger, wholly convective portion on the left and the older portion, with more

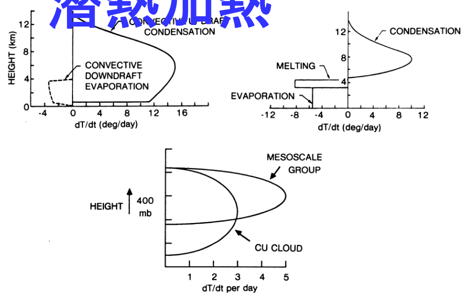
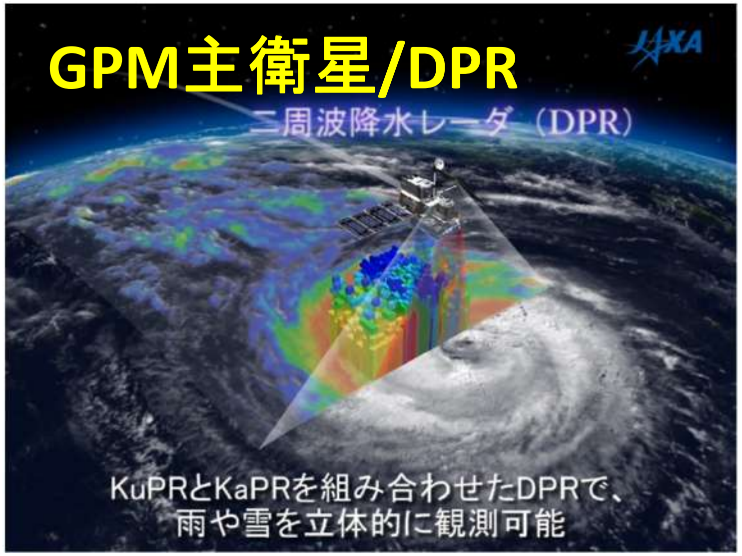


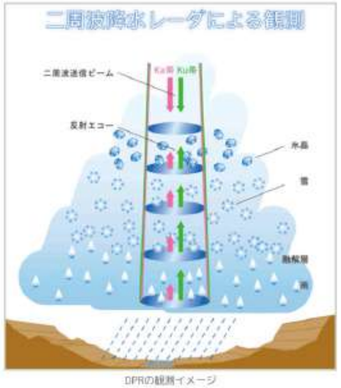

Figure 13. Schematic diagrams (after Houze, 1982) illustrating the differences between the vertical heating profiles associated with convective (left top) and stratiform (right top) precipitation. The lower diagram contrasts the hypothesized heating profile that would be associated with active convective cells only against that postulated to be produced by a cluster such as illustrated in Figures 9a and b and 12a and b, where there is a significant contribution from stratiform rain. Note that the more realistic cluster has a higher level at which the maximum heat release is hypothesized to occur. Note also that

# Contents: TRMM Report of the SSG

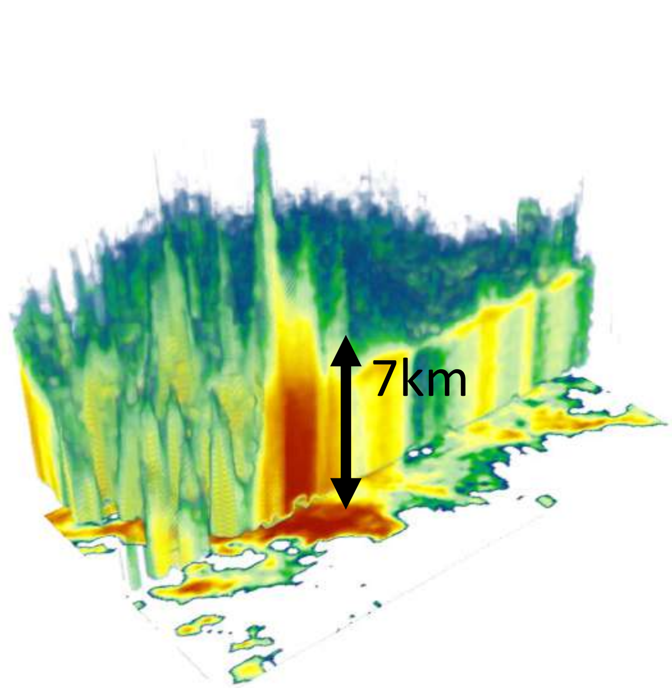
# 衛星搭載降雨レーダによる雨の立体観測

**TRMM PR**　（Ku）（熱帯降雨観測衛星）　35N-35S　1997.11-2015.4
**GPM DPR**（Ku＋Ka）（全球降水観測）　65N-65S　2014.2.28-現在

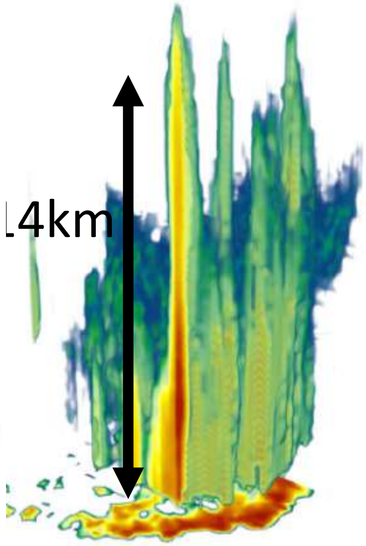


メソスケールに組織化した雨域




背の高い雨域



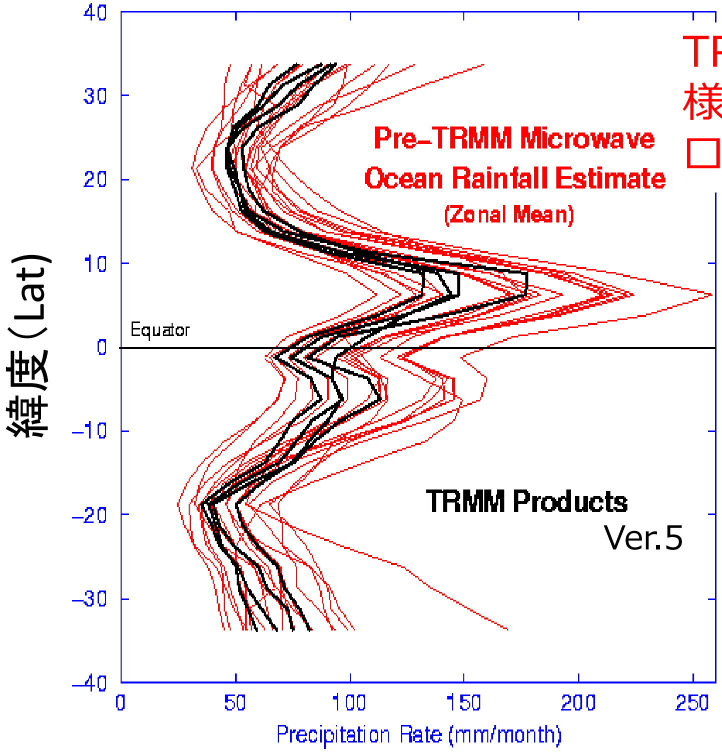

Plot by A. Hamada

衛星搭載レーダで雨を立体的に捉えることによって、高さや対流・層状の区別など、雨の降り方の特徴を地球上のありとあらゆる条件下で把握できるようになった。

# TRMMによる降水推定の不確実性低減　Flying Rain Gauge

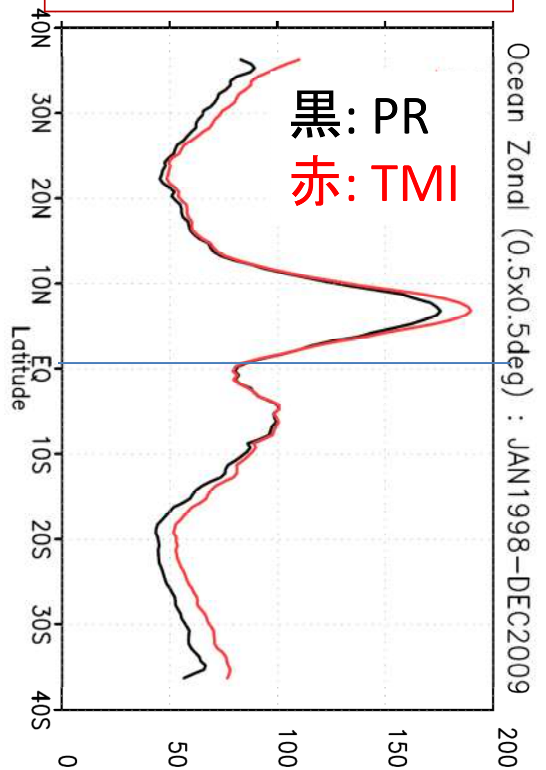
衛星降水レーダ導入前及び
TRMM初期(TRMM.v5)（Adler, 2001 )

TRMM以前の
様々なマイク
ロ波衛星観測




各緯度での平均降雨 (mm/month)

衛星降水レーダ導入後
（TRMM.v7）



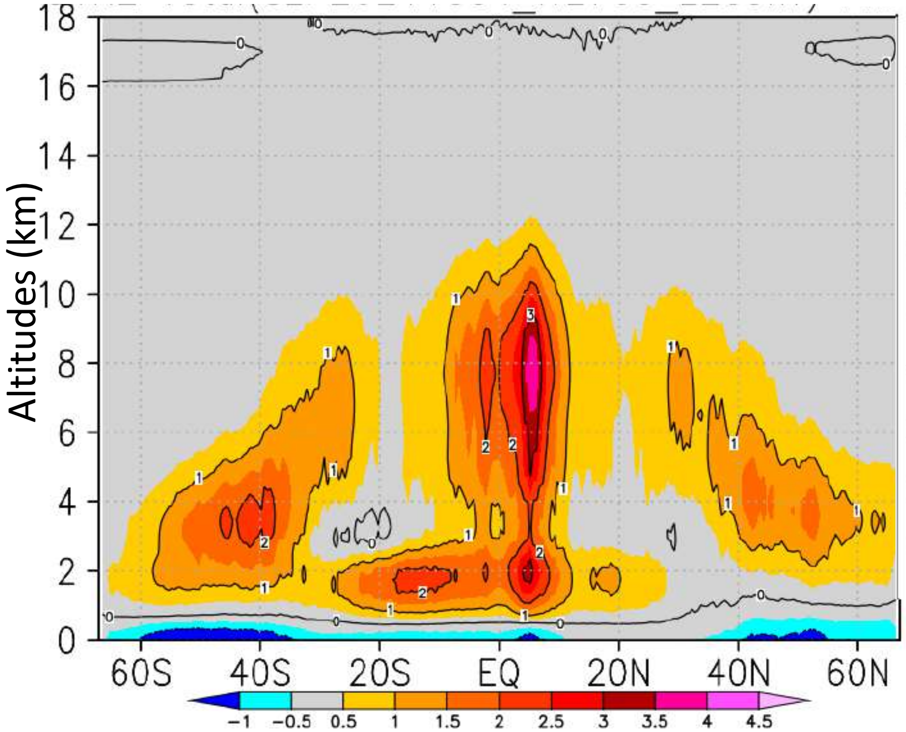

各緯度での平均降雨量 (mm/month)

JAXA EORC
久保田博士提供

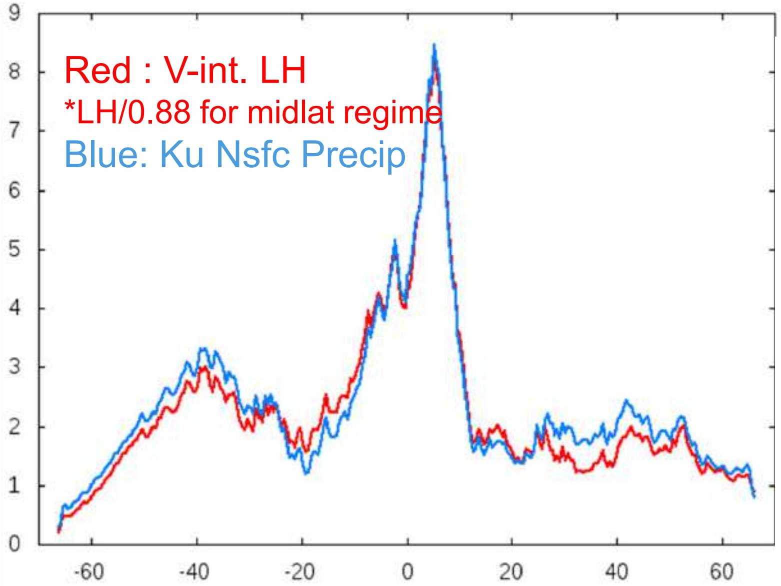
- TRMM以前の衛星搭載マイクロ波放射計による降雨推定はばらつき大
- 衛星搭載降水レーダ観測により、両者が一致、マイクロ波降雨推定手法が高精度化
  →マイクロ波放射計降雨推定手法に対する降水レーダの影響は非常に大きい。

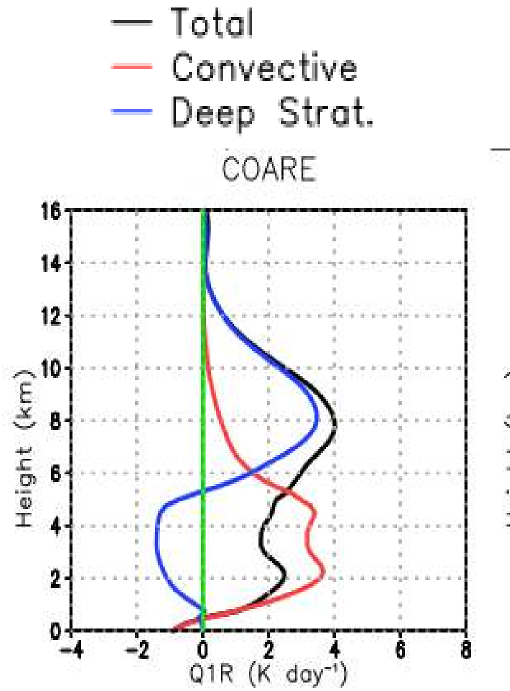
# GPMによる4次元潜熱加熱推定　GPM V07 Spectral Latent Heating

Zonal Average  AMJ2014
Q1-QR SLH V07_ITE760




Integrated LH vs KuPR Precipitation
AMJ2014 SLH V07_ITE760



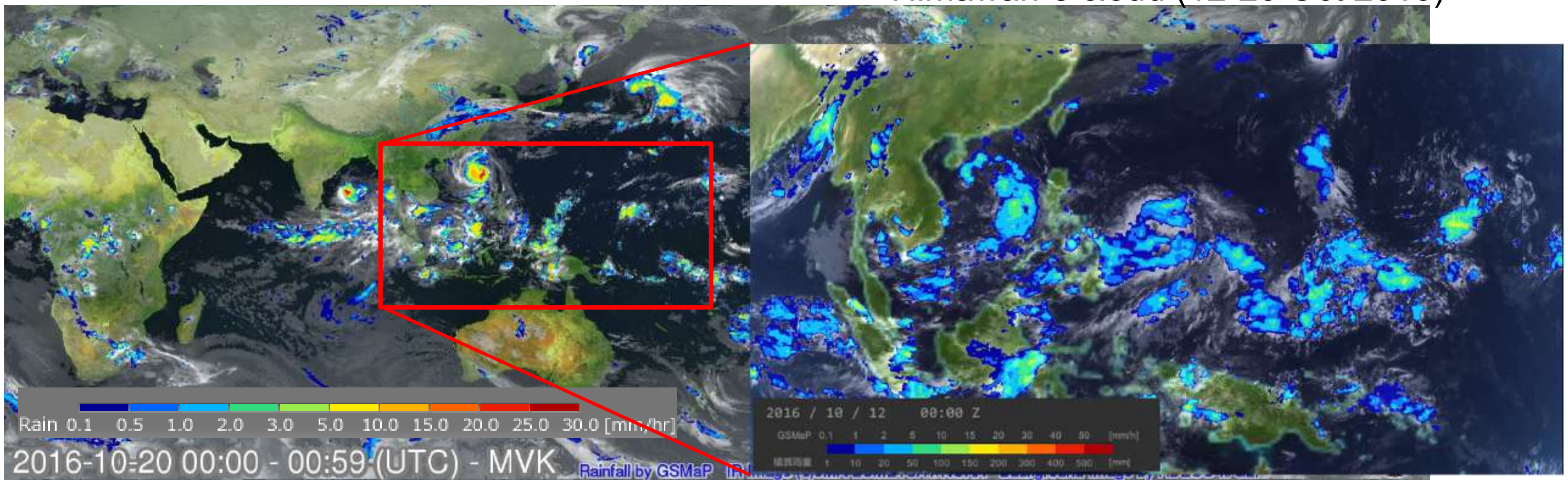




- ほぼ全球の降水に伴う４次元潜熱加熱の推定（Level2）
- 熱帯降水潜熱プロファイルと中緯度降水潜熱プロファイルの違い
- 対流性降雨（congestus, deep)と層状性降雨の加熱表現

# Global Satellite Mapping of Precipitation (GSMaP)

http://sharaku.eorc.jaxa.jp/GSMaP/

GSMaP_NRT hourly rain with Himawari-8 cloud (12-20 Oct 2016)





- **GSMaP is a blended Microwave-IR product and has been developed in Japan toward the GPM mission.**
  - **U.S. counterpart is "IMERG"**
  - **GSMaP (v6) data was reprocessed as reanalysis version (GSMaP_RNL) since Mar. 2000 period , and was open to the public on Apr. 2016, and new version, GSMaP (v7) was released on 17 Jan. 2017.**
  - **GSMaP realtime product (GSMaP_NOW) in the domain of GEO-Himawari, GSMaP Riken Nowcast (GSMaP_RNC) data developed by RIKEN/AICS (Otsuka et al. 2016) are now available from JAXA/EORC ftp site.**

高解像度、高頻度の全球降水マップデータ公開

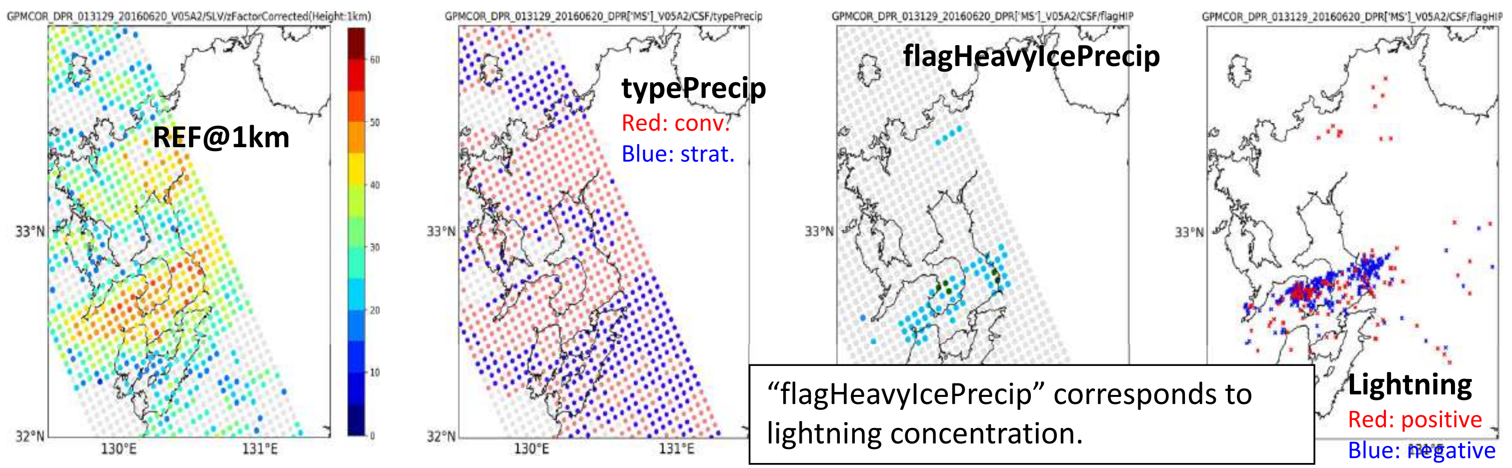
JAXA EORC
久保田博士提供

# GPM DPR 固体降水情報の抽出と地上検証

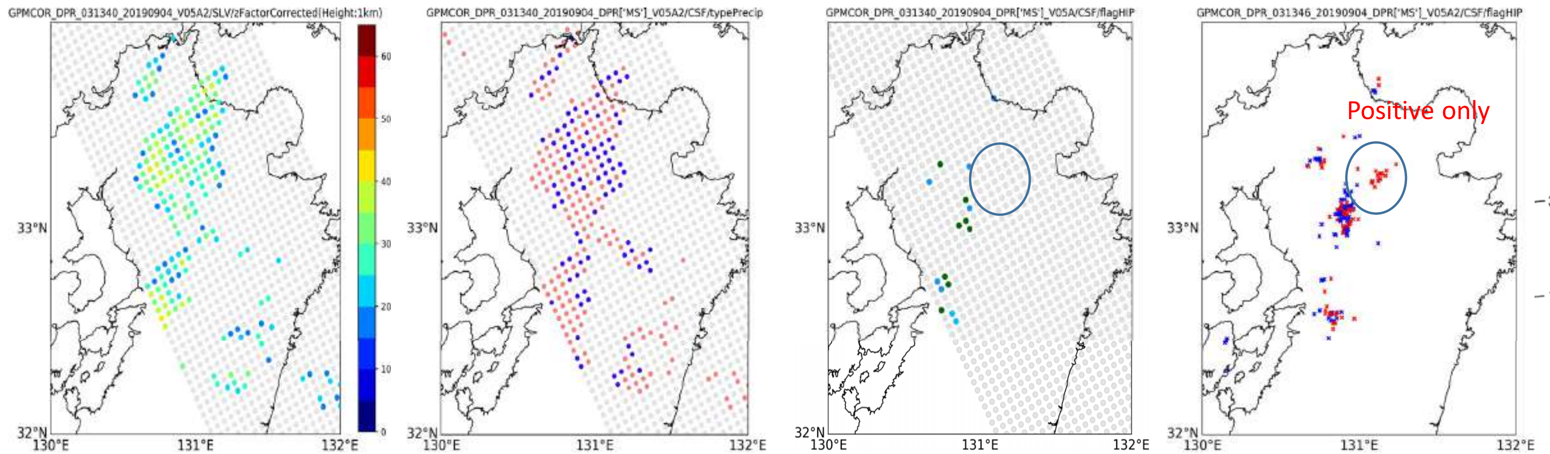
## “flagHeavyIcePrecip (by Iguchi)” and lightning activity

Kenji Suzuki

**Case 1**: Baiu frontal heavy rain on 20 June 2016




**Case 2**: Local afternoon thunderstorm on 4 September 2019

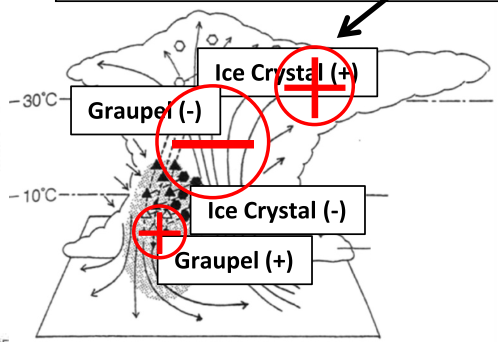



Two case studies: We confirmed that **“flagHeavyIcePrecip” may give us information on lightning activity**.

Future works: Comparison with **“BinMixedPhaseTop”** and **“flagGraupelHail”**

Now, other 26 cases that GPM/DPR observed thunderstorms during warm season from 2014 to 2020 in Japan are being investigated.

Absence of “flagHeavyIcePrecip” may indicate positive charge in upper layer.




Takahashi et al. (1999)

# 潜熱：Significance of Cumulus Congestus Rainfall

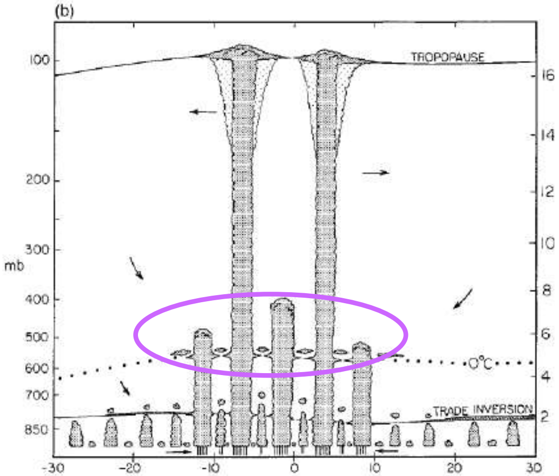
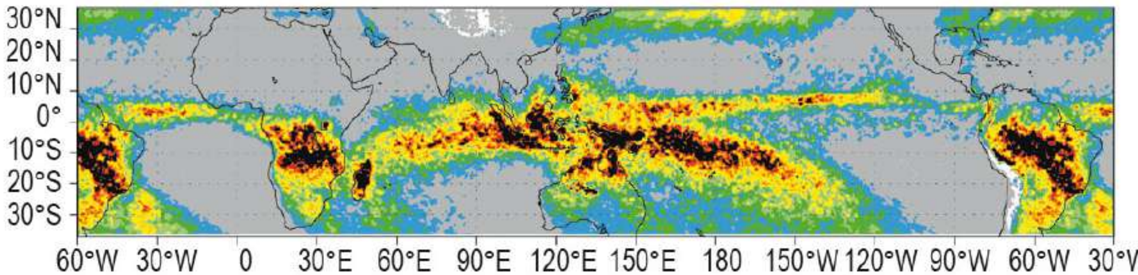



FIG. 13. (*Continued*) cloud types are indicated: shallow cumulus, cumulus congestus, an mulonimbus. Within the shallow cumulus classification, there are two subdivisions: forcec active cumulus. Three stable layers are indicated: the trade inversion, the 0°C layer, an tropopause. Shelf clouds and cloud debris near the trade and 0°C stable layers represent detrain there. Cirrus anvils occur near the tropopause. Considerable overshooting of the trade anc stable layers occurs in the equatorial trough zone. Arrows indicate meridional circulation. Alth double ITCZ is indicated, representing IOP-mean, this structure is transient over the warm and a single ITCZ often exists.

TOGA-COARE

Johnson et al. 1999

高度7.5kmの潜熱加熱 （Q1-QR） MCS（深い降水システム）




高度2.0kmの潜熱加熱 （Q1-QR） Cumulus Congestus

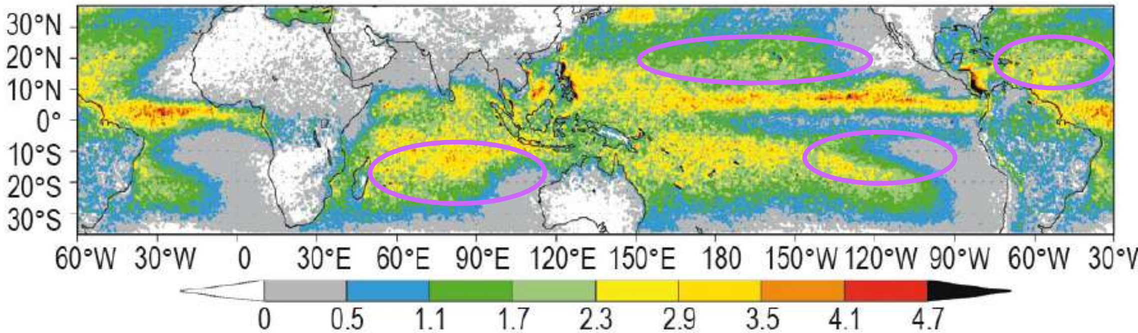



**Figure 5.9** Global distributions unconditional mean Q1–QR (apparent heat sourc minus the radiative heating) averaged for December–February seasons of 1997–2005 Upper panel (a) shows those at the level of 7.5 km and the lower panel (b) is for the 2.0 km. Unit in the gray scale is K $d^{-1}$.

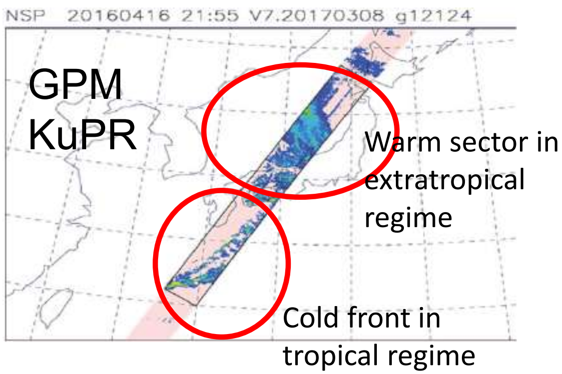
TRMM Latent Heating

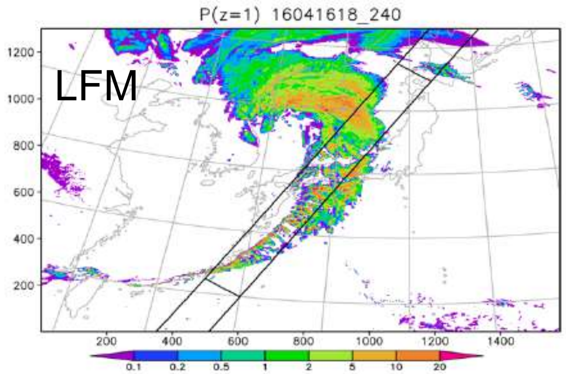
Takayabu et al. 2010

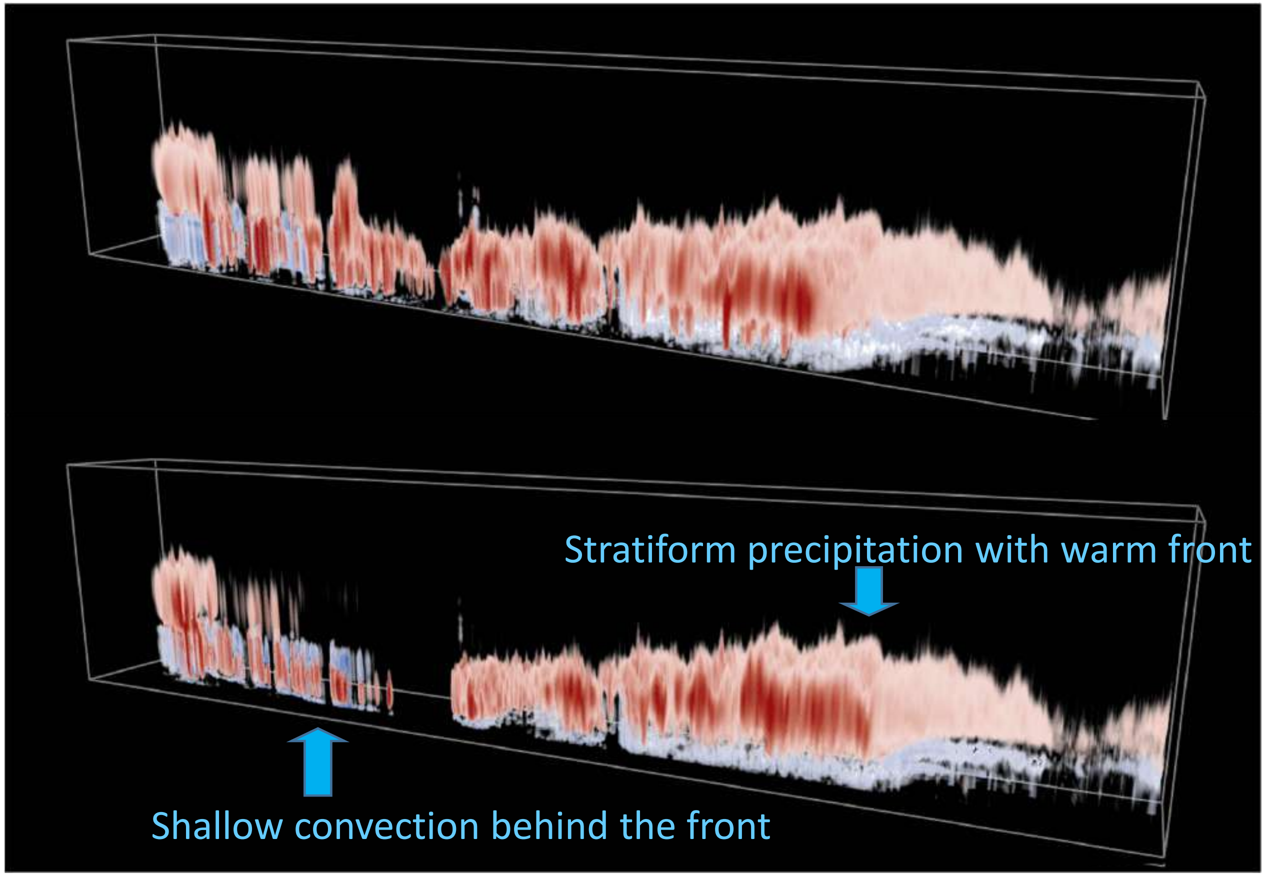
雄大積雲降水の重要性の認識・雄大積雲域の発見→モデルバイアスの解釈

# GPM-Retrieved SLH Latent Heating :

16Apr2016  An Extratropical Cyclone



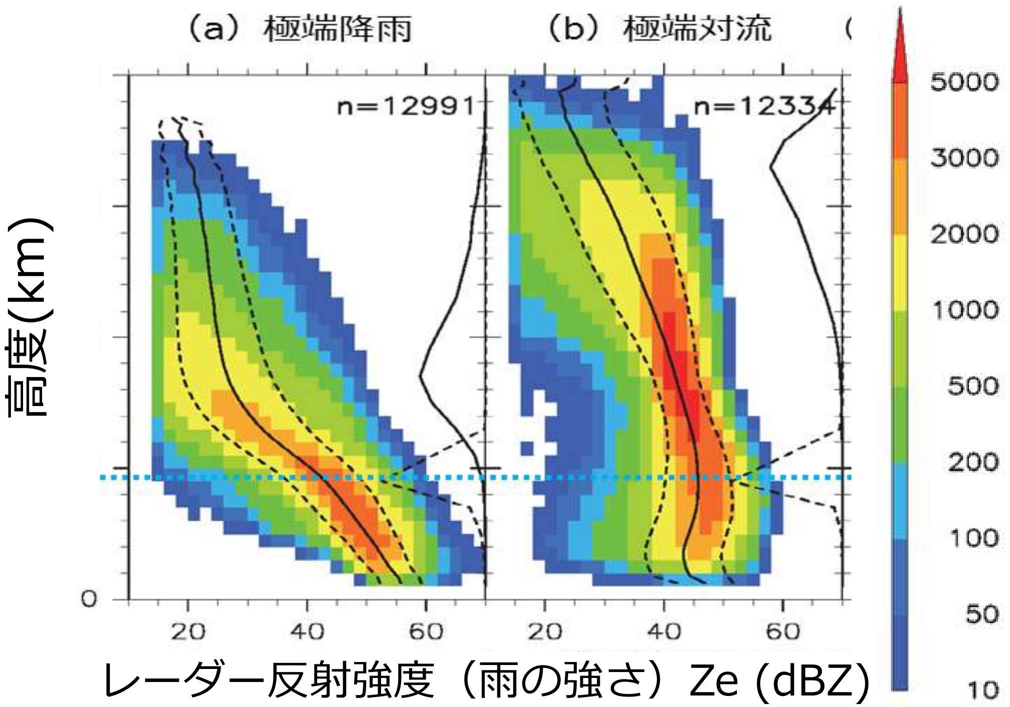




潜熱データの副産物：降水構造が明瞭にみえる

Plot by A. Hamada

# Extreme Rainfallに関する「常識」の刷新：２種類の豪雨

TRMM 降雨レーダ：**極端降雨**と**極端対流** (上位 0.1%)

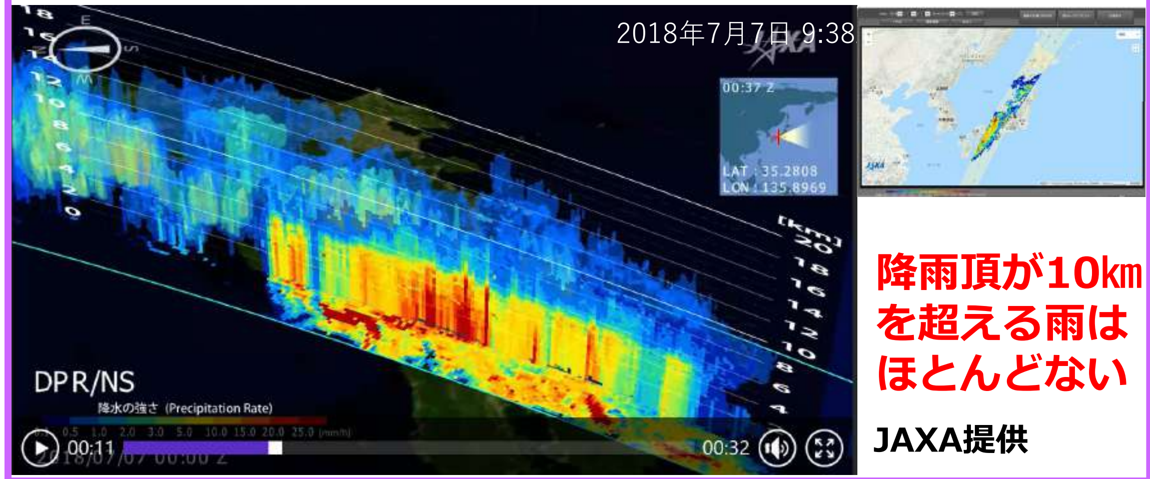



2001年9月-2012年8月**8500万個以上**の雨域統計から約300㎞四方のローカルな極端降雨（最大地上降雨強度）・極端対流（40dBZ最大高度）→双方の閾値を満たすのは僅か10%

**➡極端降雨は極端に高い対流システムから降らない。**

(Hamada et al. 2015, Nature Comm)

GPM DPR による**2018年7月豪雨**の観測



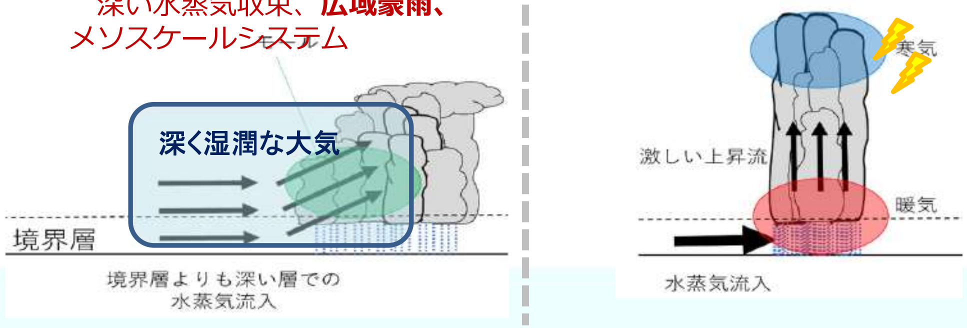

**降雨頂が10㎞を超える雨はほとんどない**

**JAXA提供**

**2種類の豪雨**

１．非常に湿潤な大気
→組織化した降水域
深い水蒸気収束、**広域豪雨、**
メソスケールシステム

２．不安定な大気→激しい対流
積乱雲、雷雲、局地的豪雨、スーパーセル



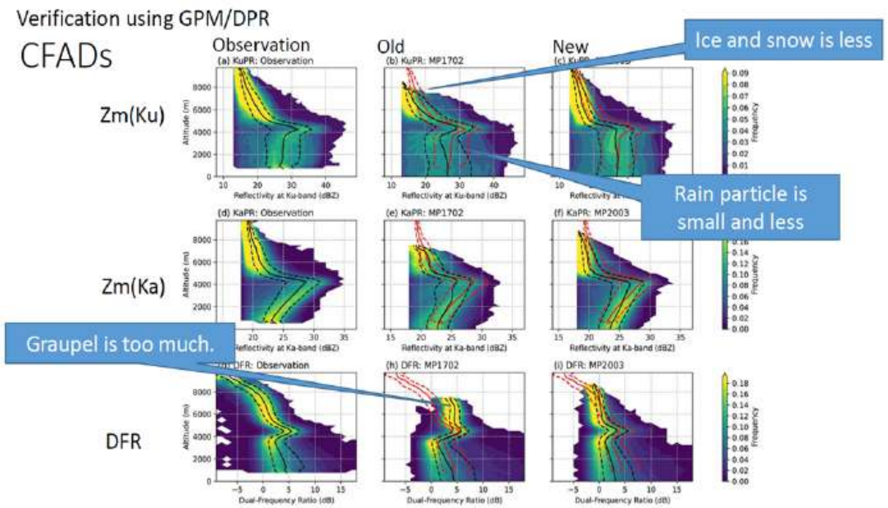

Schematics by Dr. H. Tsuji

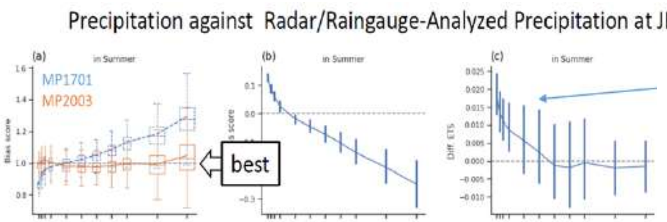
# 数値モデルとのコラボレーション

JAXA EORC
山地博士提供

## Verification of the new scheme using GPM/DPR

Cloud microphysics were changed by comparing the model with the GPM obs.




Prediction accuracy of weak rain is significantly improved.

Dr. Y. Ikuta, Dr. K. Okamoto

雲微物理モデルの改良

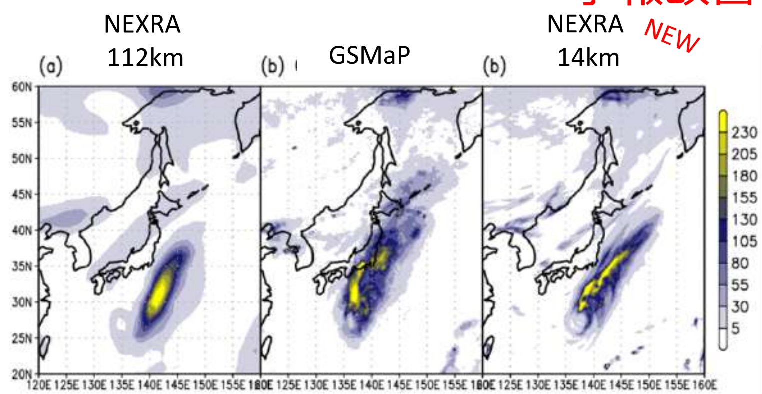
## Updates of NEXRA system

データ同化
・予報改善

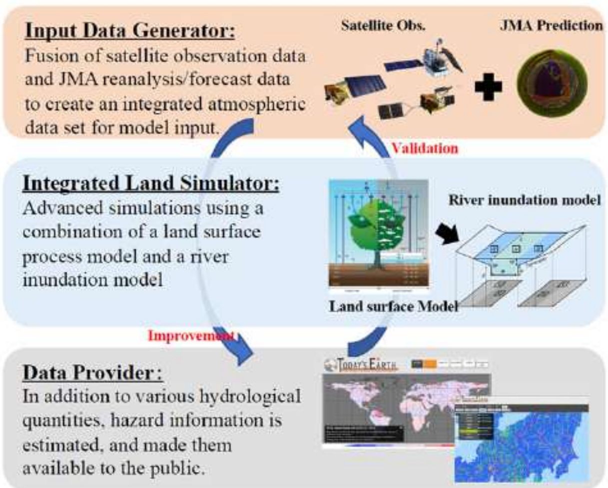
NICAM-LETKF JAXA Research Analysis

A 5-day semi-realtime weather prediction system, assimilating GSMaP.
Co-developed by AORI, RIKEN, and JAXA.

PI: Dr. T. Miyoshi




## Updates of Today's Earth system




水文モデルへの応用

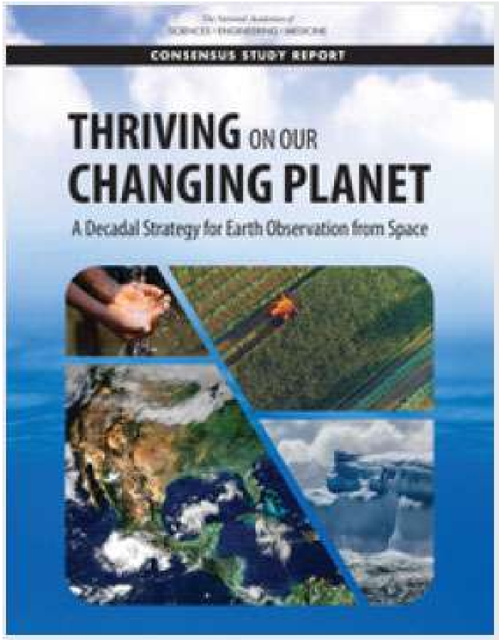
Prof. K. Yoshimura

Aerosol, Cloud, Convection and Precipitation

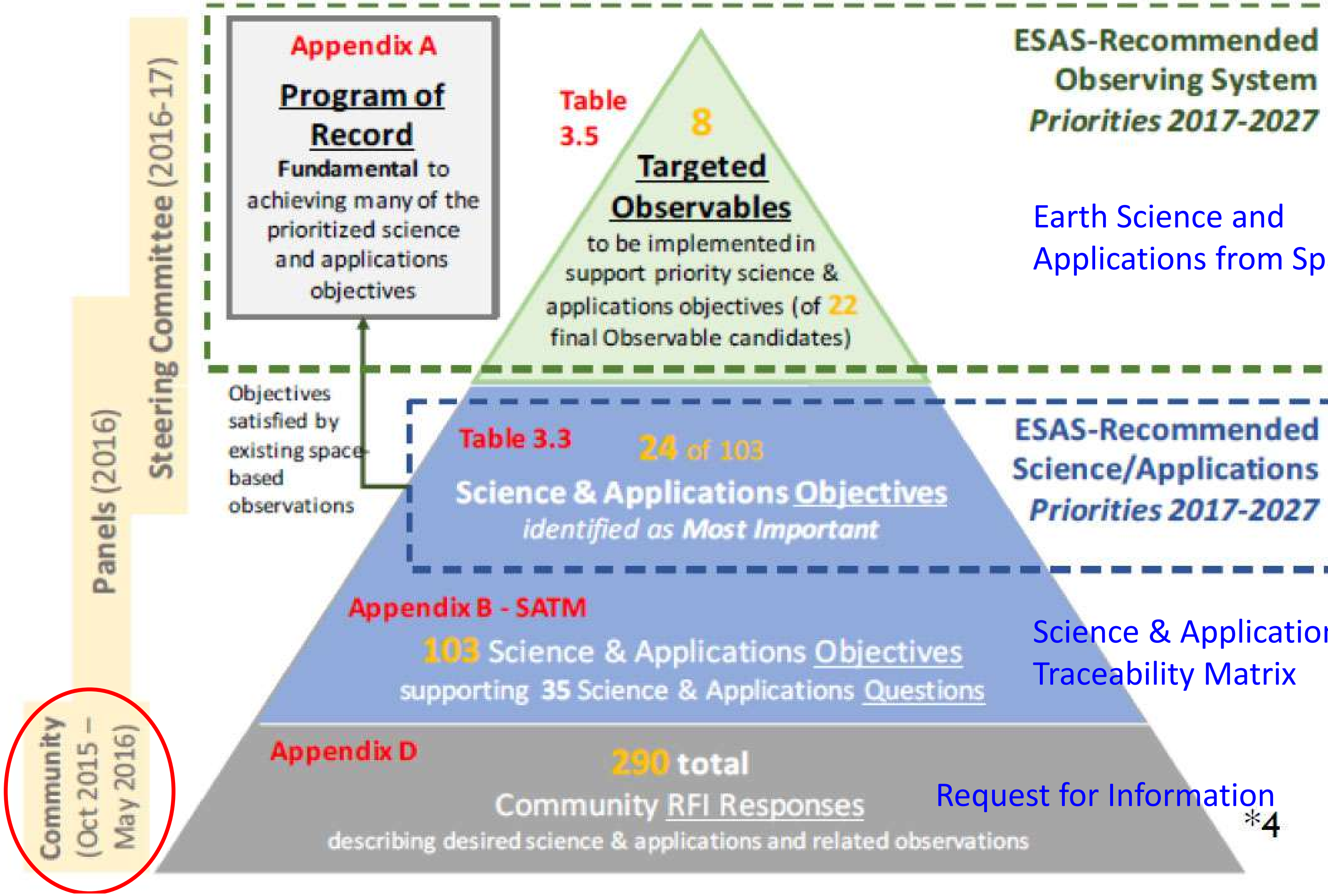
# ACCP

# Decadal Survey 2018

ESAS 2017




National Academies



# Designated

- $500Mを超えそうなものについては CATE方式*[12]に則り試算、それ以外は通常試算

*13

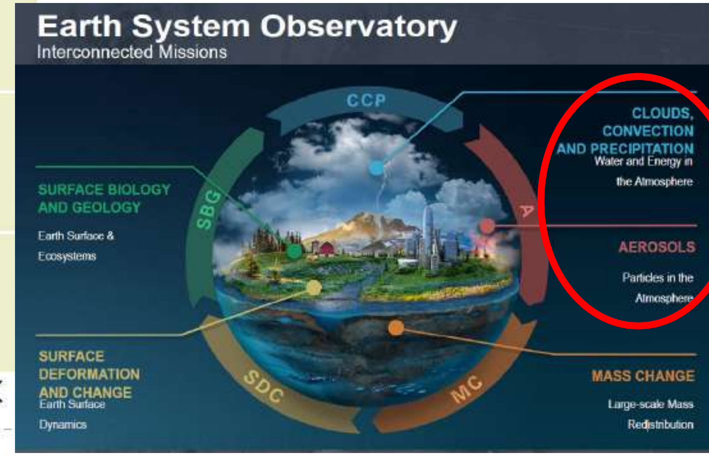
| Targeted Observable | Science/Applications Summary | Candidate Measurement Approach | Cost Cap |
|---|---|---|---|
| Aerosols | **Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their effects on climate and air quality | Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform | CATE cap $800M |
| Clouds, Convection, and Precipitation | **Coupled cloud-precipitation state and dynamics** for monitoring global hydrological cycle and understanding contributing processes including cloud feedback | Radar(s), with multi-frequency passive microwave and sub-mm radiometer | CATE cap $800M |
| Mass Change | **Large-scale Earth dynamics** measured by the changing mass distribution within and between the Earth's atmosphere, oceans, ground water, and ice sheets | Spacecraft ranging measurement of gravity anomaly | Est. cap $300M |
| Surface Biology and Geology | **Earth surface geology and biology,** ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass | Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR | CATE cap $650M |
| Surface Deformation and Change | **Earth surface dynamics** from earthquakes and landslides to ice sheets and permafrost | Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction | Est. cap $500M |

※運用費を除く

☜JAXA EORC 山本氏による勉強会資料

Designated Observables

**A＋CCP**




*12 The Aerospace Corporation（https://aerospace.org/）によるミッション試算方式
*13 : DS pp.3-57 - 3-58, TABLE 3.6（一部改変）

# AOS（ACCP)アーキテクチャ選定までのロードマップ

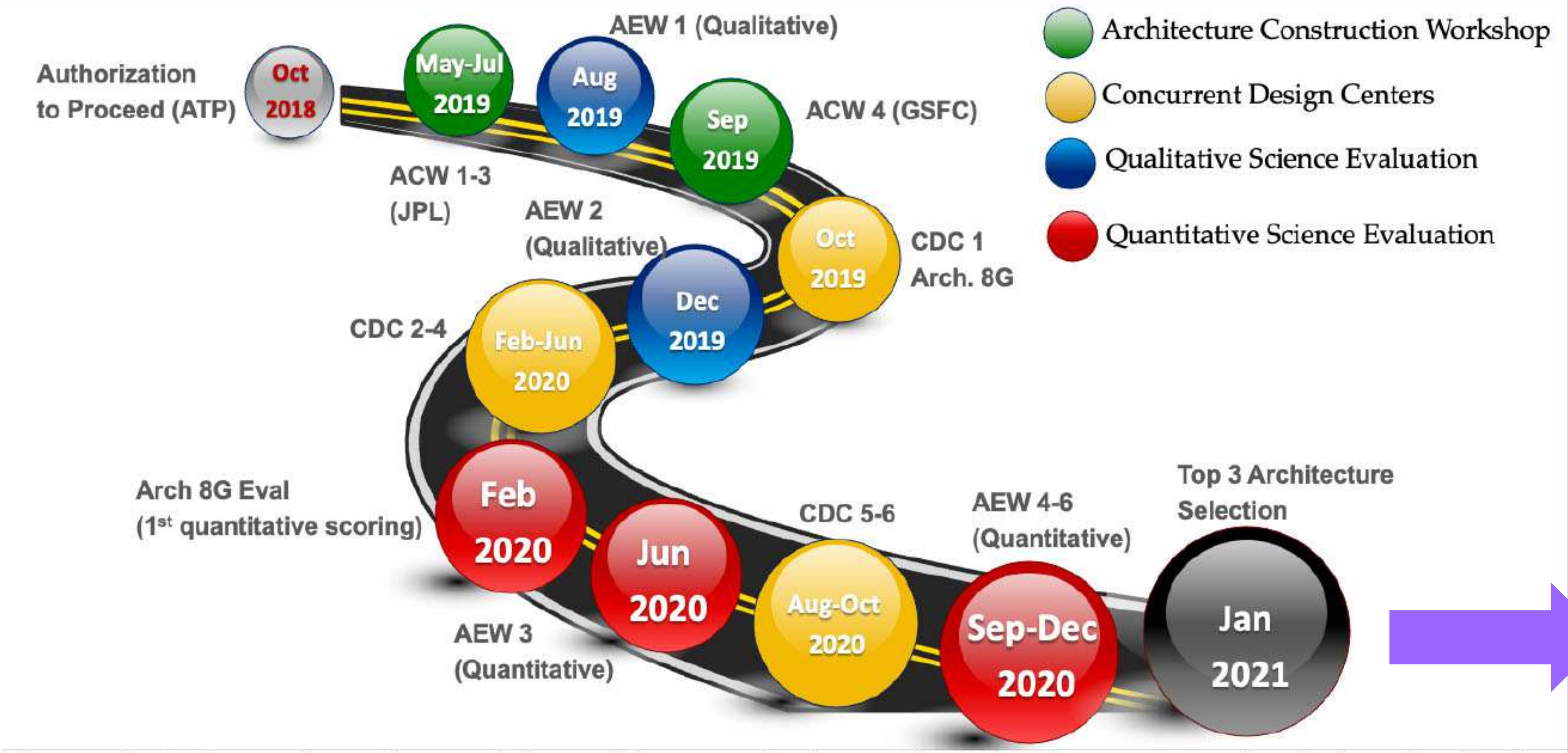



**Figure 9-1.** General roadmap of the architecture design and evaluation process that led to the final architecture selection.

Feb
2022

From Aerosol, Cloud, Convection, and Precipitation (ACCP) Science and Applications, 2021, NASA

# ACCP Narratives 2021

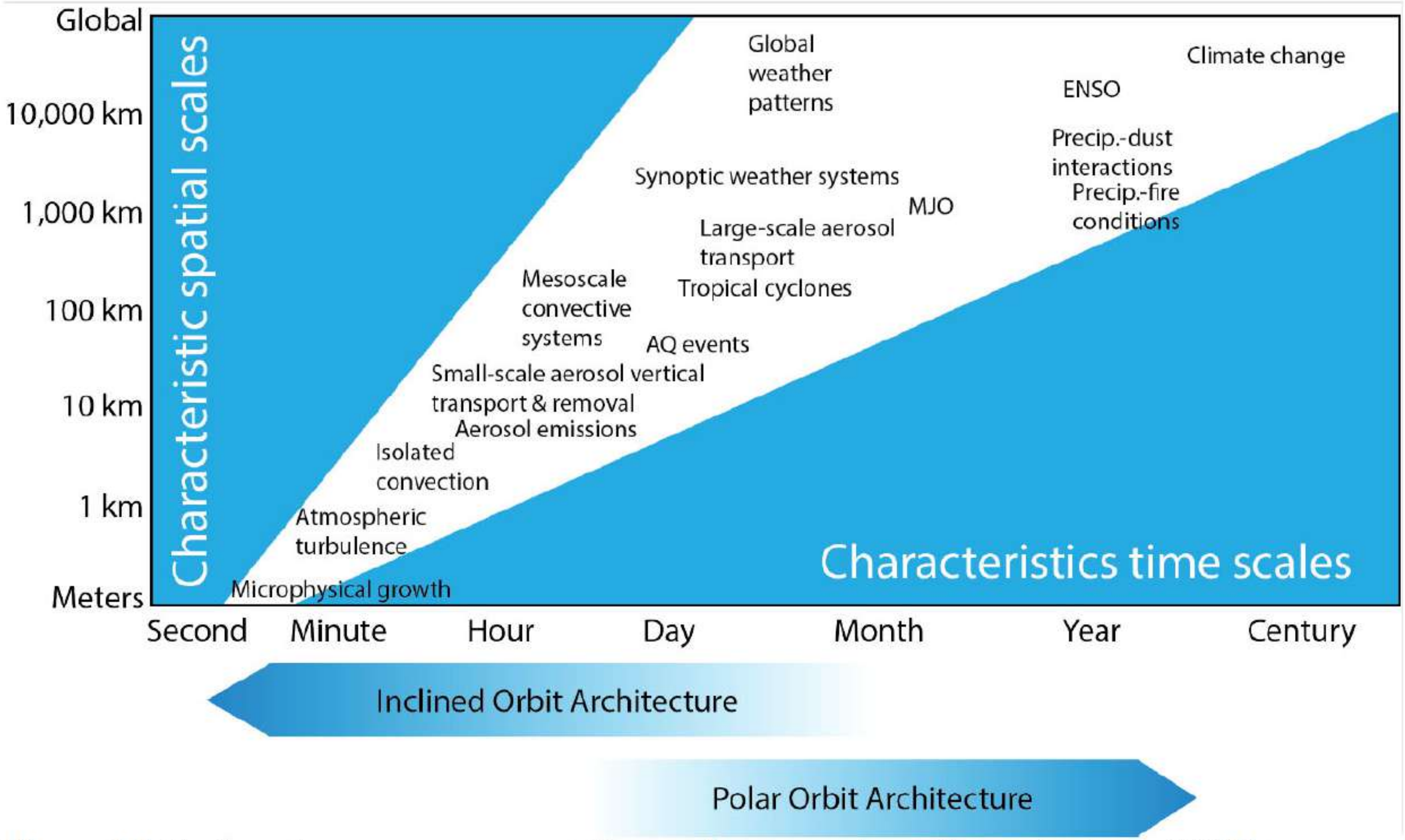



**Figure 1.1** Earth system processes across time and space scales with emphasis on ACCP processes. The architecture strategy of ACCP seeks to observe consequences of processes across multiple time scales.

# AOS (ACCP) Science Objectives

### DS Science Question

**W-4 (MI): Convective Storm Formation Processes.**
Why do convective storms, heavy preciptation, and clouds occur exactly when and where they do? (03) DC

**W-5 (MI): Air Pollution Processes and Distribution.**
What Processes determine the spatio-temporal structure of important air pollutants and their concomitant adverse impact on human health, agriculture, and ecosystems? (05, 06) DC

**C-2 (I-MI): Climate Feedback and Sensitivity.**
How can we reduce the uncertainty in the amount of future warming of Earth, improve our ability to predict local and regional climate response to natural and anthropogenic forcings, and reduce the uncertainty in global climate sensitivity?
(01, 02, 03, 04, 04, 08) R

### DS Science Objectives

**W-4a (MI).** Measure the vertical motion within deep convection to within 1 m/s and heavy precipitation rates to within 1 mm/hour to improve model representation of extreme precipitation and to determine convective transport and redistribution of mass, moisture, momentum, and chemical species.

**W-Sa (MI).** Improve the understanding of the processes that determine air pollution distributions and aid estimation of global air pollution impacts on human health and ecosystems by reducing uncertainty to <10% of vertically-resolved tropospheric fields (including surface concentrations) of speciated particulate matter (PM), ozone (03), and nitrogen dioxide (N02).

**C-2.a (MI).** Reduce uncertainty in low and high cloud feedback by a factor of 2.
**C-2.h (MI).** Reduce the IPCC ARS total aerosol radiative forcing uncertainty by a factor of 2.

### ACCP Science Goals

**G2 Storm Dynamics**
Improve our physical understanding and model representations ofcloud, precipitation and dynamical processes within convective storms

**G4 Aerosol Processes**
Reduce uncertainty in key processes that link aerosols to weather, climate and air quality related impacts.

**G1 Storm Dynamics**
Reduce the uncertainty in low- and high-cloud climate feedbacks by advancing our ability to predict the properties of low and high clouds [G2. Storm Dynamics]

**G3 Cold Cloud and Preciditation**
Improve understanding of cold (supercooled liquid, ice, and mixed phase) cloud processes and associated precipitation and their coupling to the water and energy cycles

**GS Aerosol Impacts on Radiation**
Reduce the uncertainty in Direct (D) and Indirect (I)aerosol-related radiative forcing of the climate system.

### ACCP Science Objectives

**03:** Convective Storms

**05:** Aerosol attr. & air quality
**06:** Aerosol processing, wet removal & vertical distribution

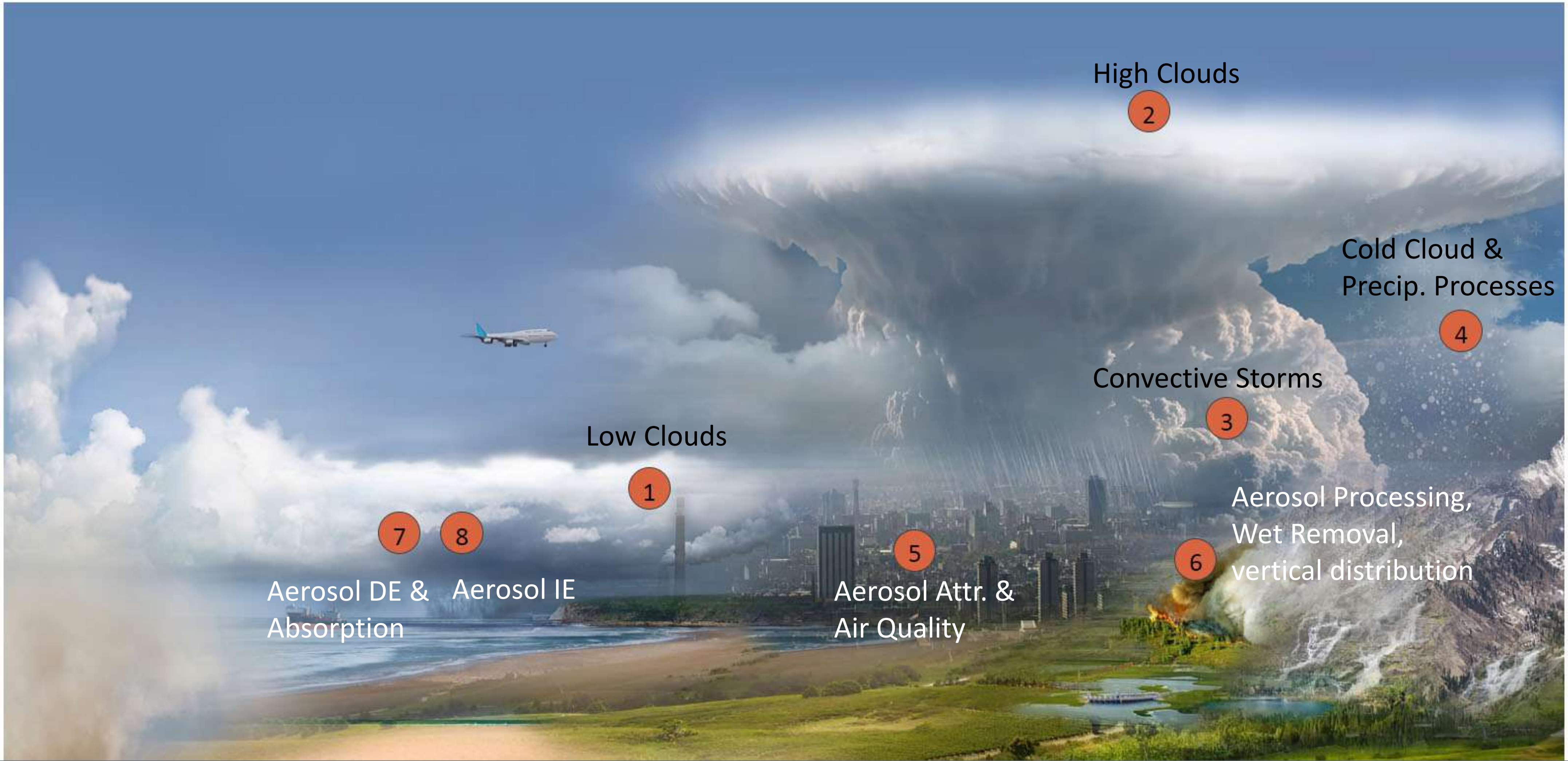
**01:**Low Clouds
**02:** High Clouds

**04:** Cold cloud & precipitation processes

**07:** Aerosol DE & Absorption
**08:** Aerosol IE

https://aos.gsfc.nasa.gov/science-goals.htm

# AOS Science Objectives：８つの目標




https://aos.gsfc.nasa.gov/science-goals.htm

**Table 6.1.** ACCP instruments are derived from technologies of Technical Readiness Level (TRL) 4 or greater. Related sets of instruments are shown here along with their airborne or spaceborne heritage.

| ACCP Instrument | Airborne Heritage | Space Heritage |
|---|---|---|
| **U.S. Radars** | AirSWOT, Airborne Precip. Radar (APR) | CloudSat, RainCube |
| **JAXA Radar** | | TRMM PR, GPM DPR |
| **HSRL Lidars** | Airborne HSRL | CALIOP |
| **Backscatter Lidar** | CPL | CATS |
| **U.S. Passive Micro. Radiometer** | CoSMIR | TWICE (IIP) |
| **CNES Passive Micro. Radiometer** | | Megha-Tropiques SAPHIR, METOP-SG (MWS, MWI, ICI) |
| **Polarimeters** | AirHARP | HARP, HARP2 |
| **Shortwave Spectrometer** | High-altitude balloon flights | CLAREO Pathfinder on ISS (2024) |
| **Longwave Spectrometer** | Airborne flights | |
| **Tandem stereo cameras** | | Star trackers, LEO/GEO cameras, MISR technique |
| **Aerosol Limb Imager** | High-altitude balloon flights | |
| **Moisture Limb Imager** | High-altitude balloon, ER2 flights | |

# ACCP ”Baseball Cards

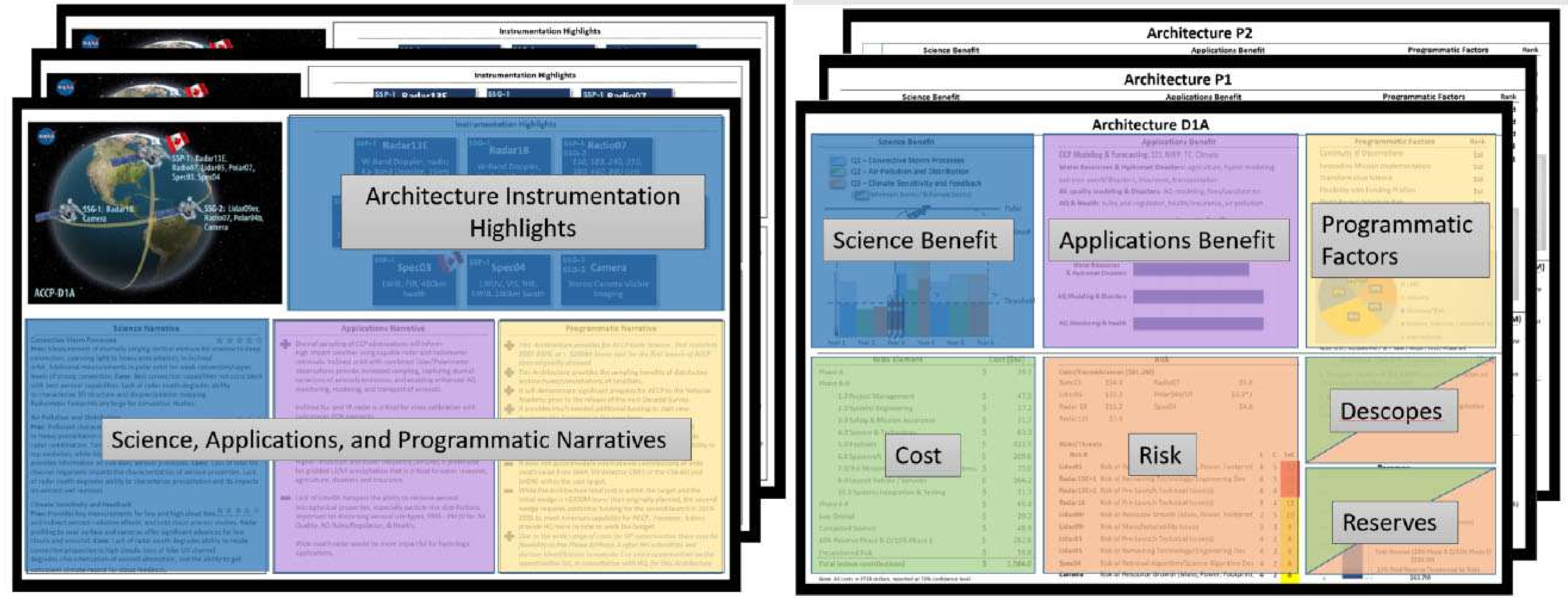



**Figure 8.3:** Categories of information included on the front and back of the ACCP “Baseball Cards.

# ACCPアーキテクチャ

- 本ページ未確定情報のため図は省略させていただきます。

- Inclined Orbit（現在55度の予定）とPolar Orbitに大型~小型をとりまぜ複数機ずつ投入する計画　(各々2028、2030年打ち上げ予定）
- JAXA（日本）、CNES(フランス）、CSA（カナダ）等のInternational Collaborationが計画されています。
- JAXAからはInclined OrbitへのKu帯DopplerRadar搭載衛星の投入が計画されています。

# TRMM・GPM・ACCP：ここまでの感想

- TRMM・GPMに比較してターゲットとする科学が非常に広範
- AとCCPでは利害が対立する場合がある
- コストキャップがControlling Factor
- 衛星の大小ミックスの可能性追求
- 時間をかけた徹底的な議論による繰り返しの調整

- 日本は人数が圧倒的に少ない
- 日本は得意分野を活かして頼りにされる
（ただし、「得意分野の地位」は安定ではない）
- 国際的な議論の中に居ることで大きな数の利点を得ることができる
- ただしACCPはTRMM・GPMよりさらにNASAのミッション
→自国が中心となって議論するミッションを持つ必要も：バランス

# 日本の地球衛星観測について

- 人材育成
- 日本の地球衛星観測のプログラム化の必要性
  （重要な観測の継続と高性能化による科学的貢献）
- 高度な技術力に基づく積極的な国際協力
- 科学的要請についての十分な議論力の向上

  →（例）AOS　JAXA＋科学コミュニティ：現在大変頑張っている

  →人数が必要、人材育成が必要
- 日本が地球衛星観測の一翼を担っていく意義を、（地球衛星観測関係者のみでなく）より広いコミュニティで議論し明確化していく力が必要