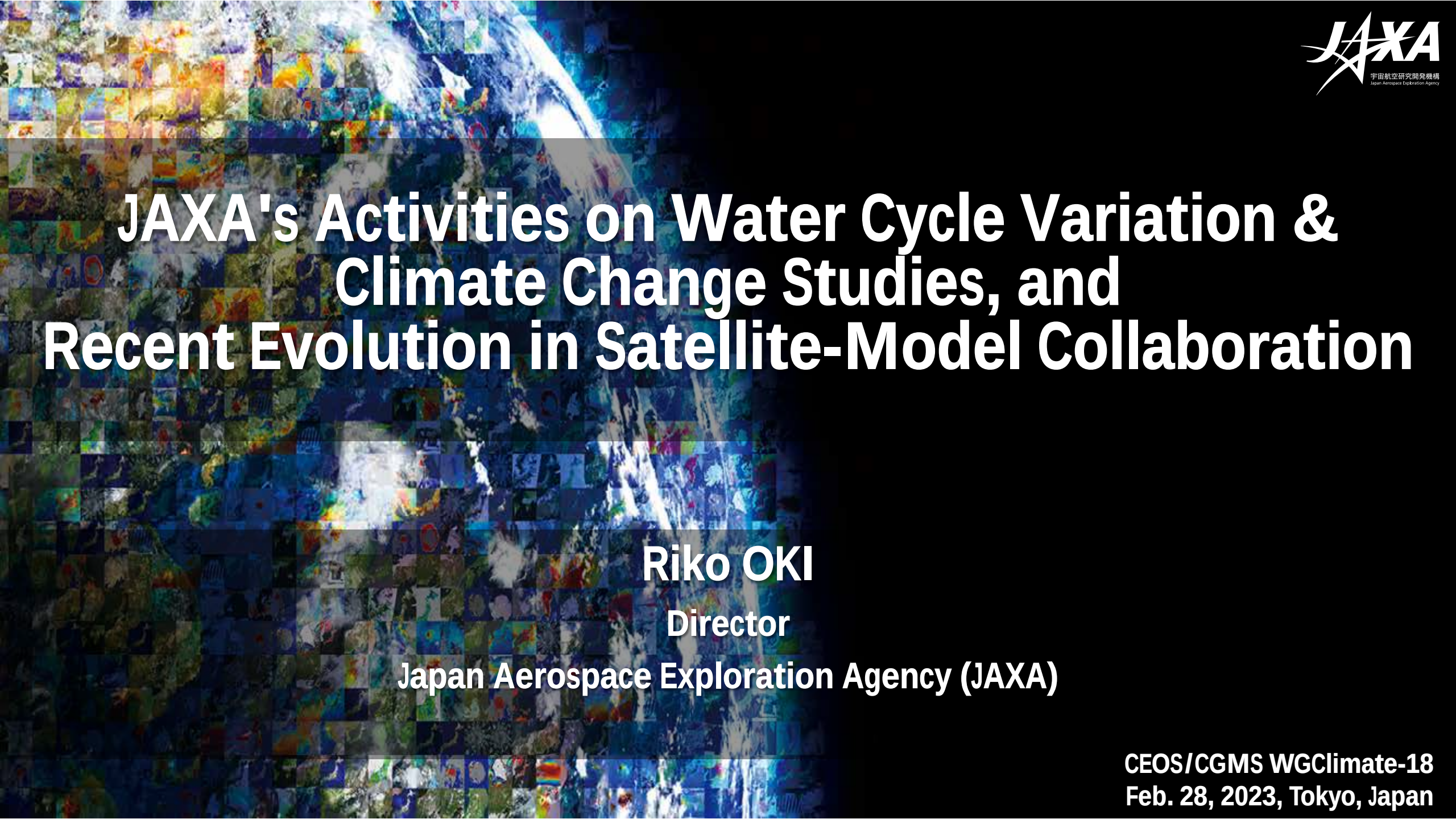


JAXA's Activities on Water Cycle Variation & Climate Change Studies, and Recent Evolution in Satellite-Model Collaboration

Riko OKI

Director

Japan Aerospace Exploration Agency (JAXA)

CEOS/CGMS WGClimate-18

Feb. 28, 2023, Tokyo, Japan

Japanese Earth Observation Satellites/Sensors

Targets (JFY: Apr-Mar)

2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025

Disasters Management & Land Monitoring

JERS1/OPS, SAR (1992-1998)
ADEOS-I/AVNIR
ALOS/AVNIR2, PALSAR (2006-2011)

[Land and disaster monitoring]
ALOS-2 / PALSAR-2
[Land and disaster monitoring]
ALOS-4/SAR
[Land and disaster monitoring]
ALOS-3/Optical

Climate System

•Climate change

ADEOS-I/OCTS (1996-1997)
ADEOS-II/GLI (2003)

[Vegetation, aerosol, cloud, SST, ocean color]
GCOM-C / SGLI
[Cloud and aerosol 3D structure]
EarthCARE / CPR
with ESA

•Water Cycle

ADEOS-II/AMSR (2003)
Aqua/AMSR-E (2002-2011)

TRMM / PR
[Precipitation 3D structure]
with NASA
ACCP Pre-phase A
PMM(TBD) Phase A
GPM / **DPR**
with NASA
[Wind, SST , water vapor, precipitation]
[Wind, SST , water vapor, rainfall]
GCOM-W / AMSR2
GOSAT-GW/ AMSR3 & TANSO-3

•Greenhouse gases

[CO_2, CH_4]
GOSAT / FTS, CAI
with MOE
MOE
[CO_2, CH_4, NO_2]
[CO_2, CH_4, CO]
with MOE
GOSAT-2

JMA geostationary meteorological satellites

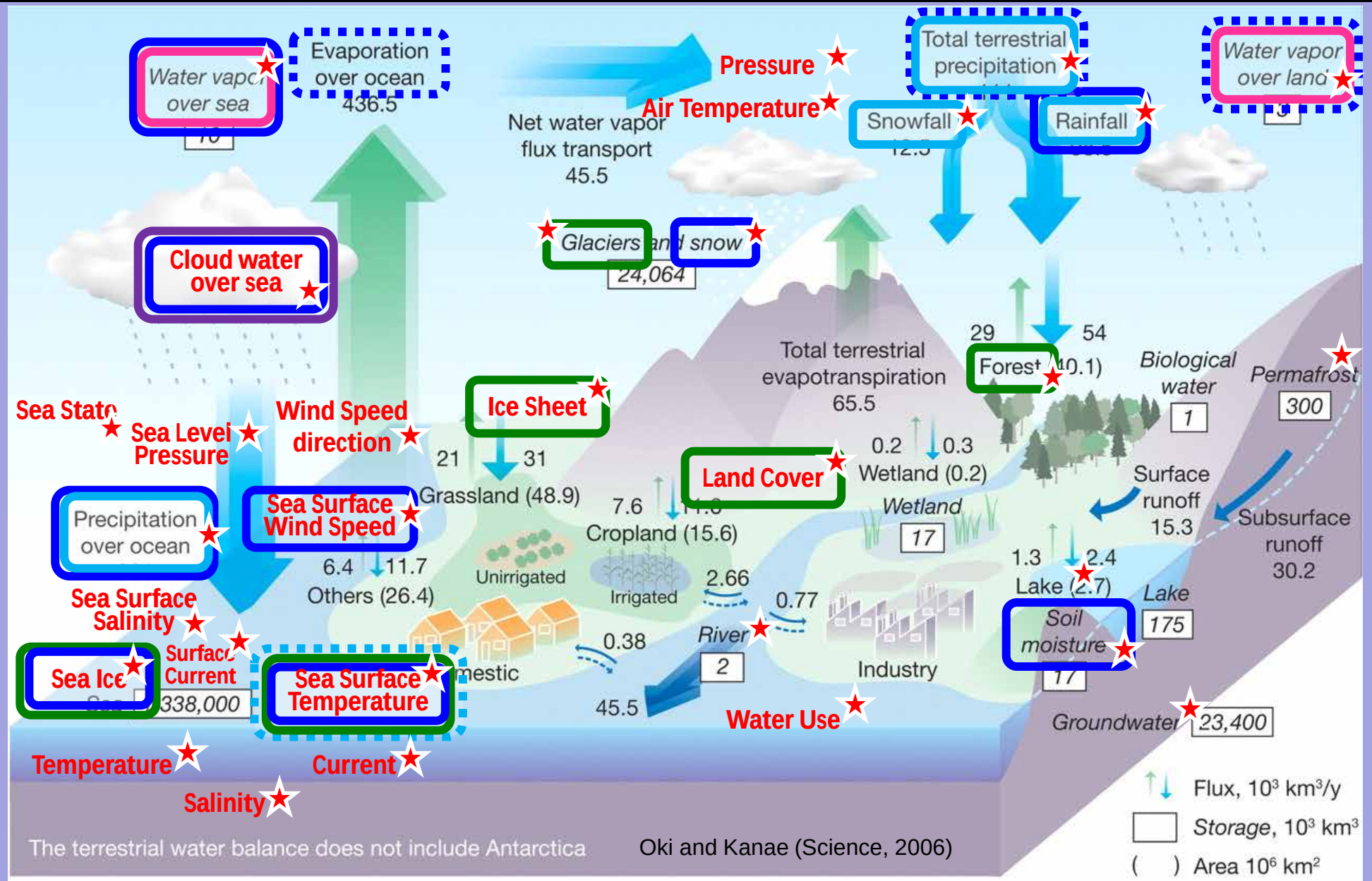
MTSAT-1R
(Himawari-6)
Himawari-10/11 planning
MTSAT-2 (Himawari-7)
[Cloud, aerosol, SST]
Himawari-8
Himawari-8 (standby)
Himawari-9 (standby)
Himawari-9

Mission status: Completed | On orbit | Development | Pre-phase-A | Phase-A

Water Cycle, ECVs and JAXA's Satellites

JAXA's Satellites

- GOSAT
- GCOM-W
- GPM
- GCOM-C
- EarthCARE



ECVs

Essential Climate Variables

Variables enclosed by broken line are observable under some conditions

Climate Change & Global Earth Observation System

Atmosphere

Forcing (Assessing Radiative Forcing)

Interactions (Assessing Climate Sensitivity/Convection)

Extreme Weather, Cyclone Change (Number, Intensity, Storm Track)

CO2
515GtC
→790GtC
@2100 ?

Warming
1.4C→2.9C?

Global Warming by Greenhouse Effect

BC: -0.5 C?

Heating & Cooling

Water Cycle Change

Observation of Vertical & Latitudinall Cloudy/Clear Sky Distributions

Passive Microwave Radiometer: AMSR series

Cloud Radar: CPR

GHG Observing Satellite: GOSAT series

Long Lived Greenhouse Gases (LLGHGs)

Short Lived Climate Pollutants (SLCPs)

Cloud Condensation Nucleus, Inverse Umbrella Effect?

Cloud & Precipitation Change

Precipitation Radar: DPR

Global Optical Imager: GCOM-C

- Hearth Hazard
- Ecosystem Change
- Decline of Biodiversity

- Agricultural Hazard
- Weather Disaster

Human Activities

Human Society & Ecosystem
GDP Damage: 2-8% (2100)
(100-400 BUSD)

- Sea Level Rise
- Sea Ice Decrease
- Ocean Acidification
- Warming of Ocean
- Change of Ocean-ecosystem

- Extreme Weather
- Drought/Flood
- Wildfire
- Melting of Glacier & Ice Sheet

Land Use Change (DEM, Forest)

Vegetation

River Discharge

Snow & Ice, Sea Ice

Chlorophyl-a Concentration

Soil Moisture

Volcano, Undersea Volcano

Ocean Currents

SST

Land

Land Observing Satellite: ALOS series

Vegetation Lidar: MOLI

Ocean

Water-related Microwave Missions in Japan

1985 1990 1995 2000 2005 2010 2015 2020 2025 2030

Ku-band (13.8GHz) radar

1997 - 2015

From tropics to mid latitudes & from single to dual freq.

Overlap to CAL/VAL

W-band (94 GHz) radar with Doppler

2023-

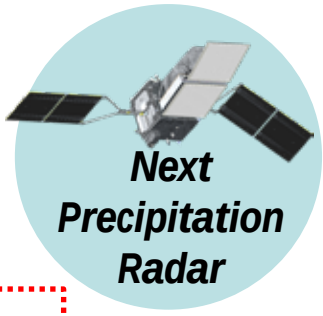
Ku- (13.6GHz) & Ka-band (35.5GHz) radar

2014 -

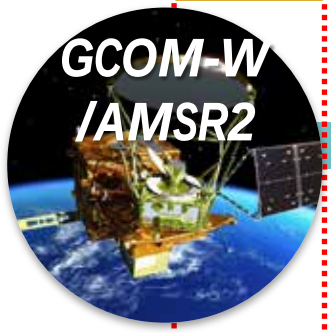
C-to-W-band microwave imager

2002 - 2011

slow rotation mode



Overlap to CAL/VAL



C-to-W-band microwave imager

2012 -

Overlap to CAL/VAL

K-band microwave imager

1987

C-to-W-band microwave imager

2002-2003

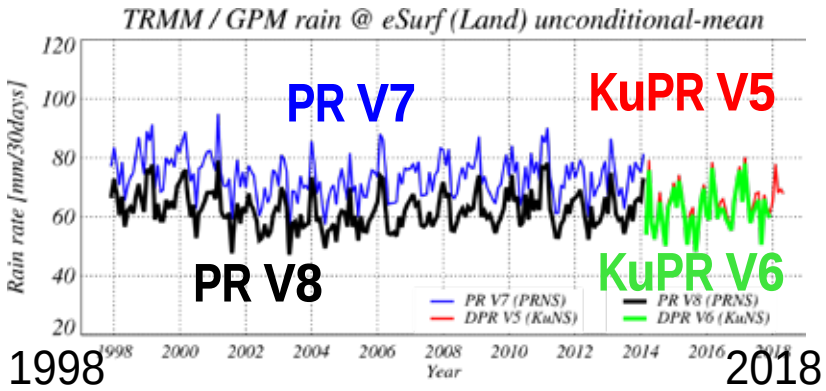
C-to-X-band microwave imager

2024 -

Monitoring of long-term precipitation radar datasets by TRMM/PR (1997-2015) and the GPM/DPR (2014-)

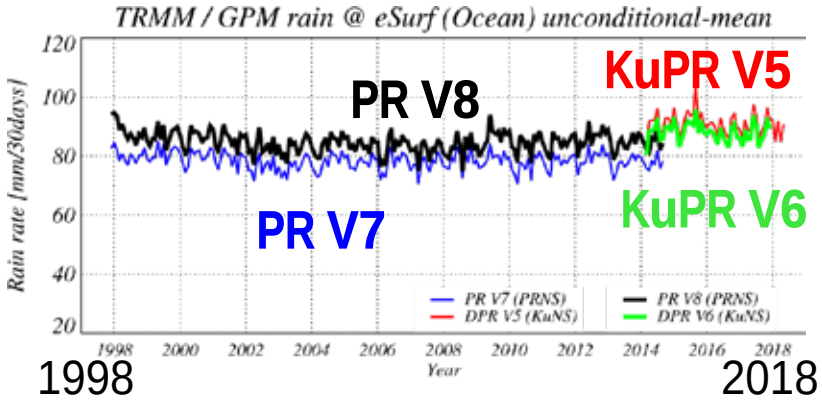
- GPM/DPR's calibration factors was changed in V05 released on May 2017, and TRMM/PR's calibration factors was also changed in TRMM/PR-L1 V8 (GPM TRMM V05) L1 released on Oct. 2017.
- Better continuity was realized in the TRMM/PR-L2 V8 (GPM TRMM V06) and GPM/DPR-L2 V06 released in Oct. 2018, by using common precipitation estimation algorithms between the TRMM/PR and the GPM/KuPR.

Over-land surface precipitation rates averaged in 35S-35N.



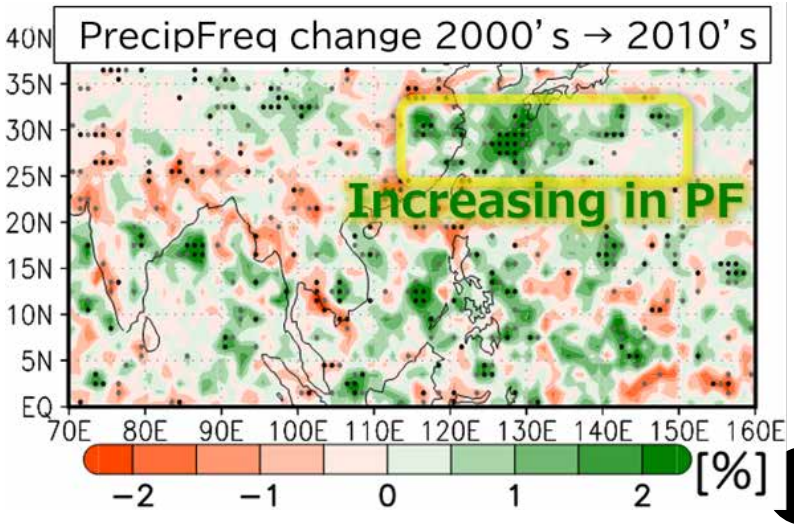
1998 2018

Over-ocean surface precipitation rates averaged in 35S-35N.



1998 2018

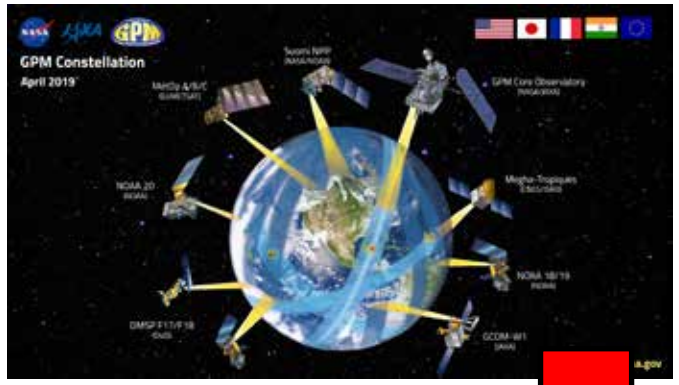
Takahashi and Fujinami (2021) showed **recent decadal enhancement of Meiyu-Baiu heavy rainfall** over the East Asia using the TRMM/PR & GPM/DPR dataset.



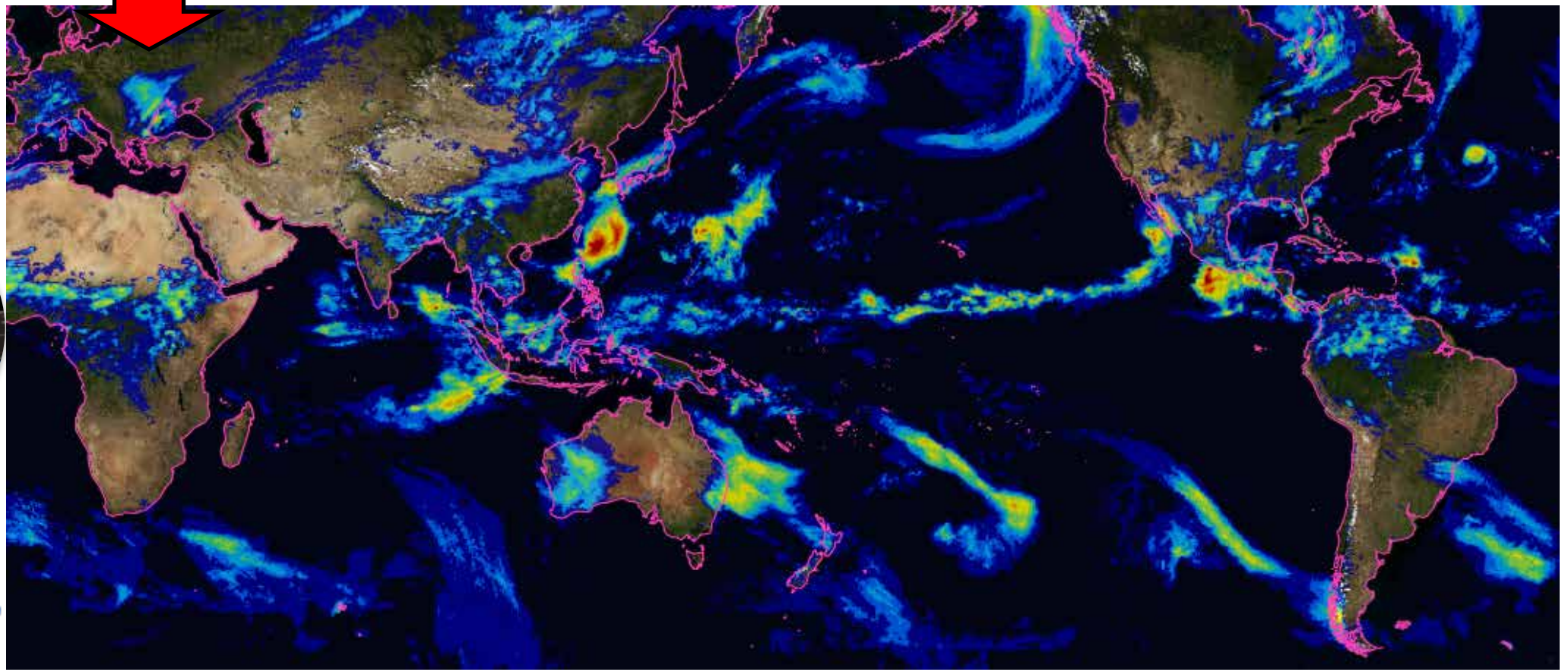
à These dataset was used long-term precipitation analyses.

Takahashi, H.G., Fujinami, H. Recent decadal enhancement of Meiyu–Baiu heavy rainfall over East Asia. *Sci. Rep.* 11, 13665 (2021).
https://doi.org/10.1038/s41598-021-93006-0
https://earth.jaxa.jp/en/earthview/2021/08/02/5584/index.html

Monitoring of Hourly Global Precipitation



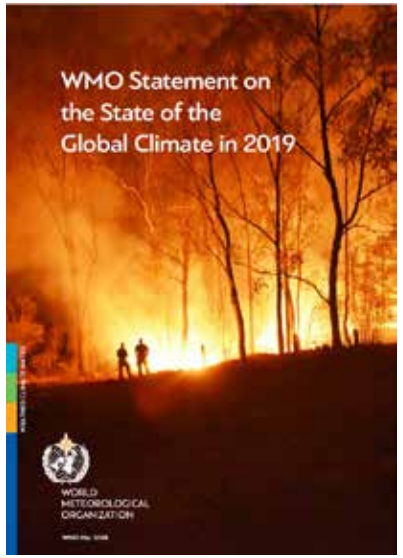
- JAXA has developed the Global Satellite Mapping of Precipitation (GSMaP) under the Global Precipitation Measurement (GPM) mission
  - GSMaP is a blended Microwave-IR product in hourly and 0.1-degree grid
  - Near-realtime & realtime availability, available since Mar. 2000
  - https://sharaku.eorc.jaxa.jp/GSMaP/index.htm



GSMaP
GLOBAL SATELLITE MAPPING OF PRECIPITATION

Monitoring of Weather and Climate

- JAXA attends WMO Space-based Weather and Climate Extremes Monitoring (SWCEM) project and provide the GSMaP product with about 22yr-climate data to National Meteorological and Hydrological Service in Asia and Pacific regions.

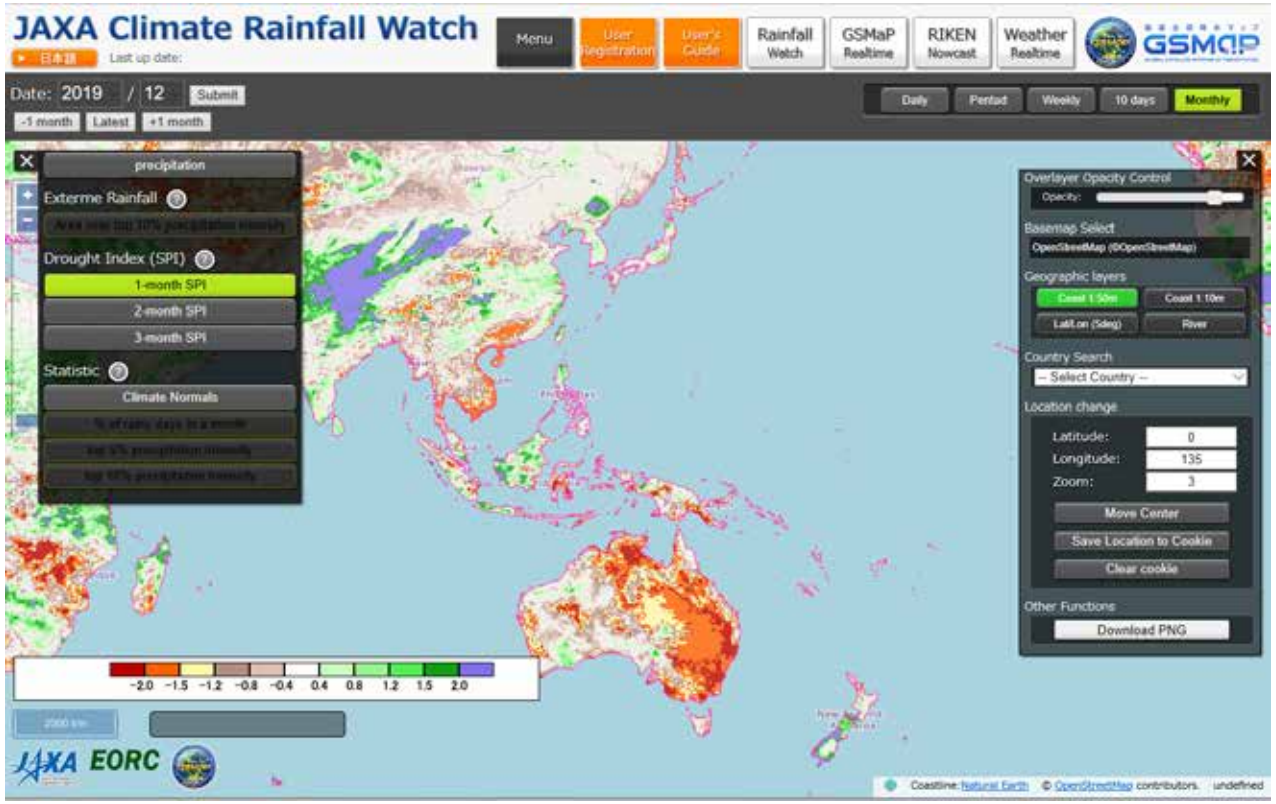


Based upon results of this WMO project, results including JAXA GSMaP were described in the 2019 Australia drought article of the WMO Statement on the State of the Global Climate 2019.

WMO Secretary-General Petteri Taalas at UN headquarters in New York (11th Mar. 2020)

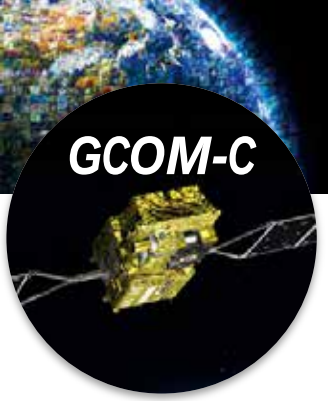
https://public.wmo.int/en/media/news/state-of-climate-report-released-un-and-wmo-chiefs

Based upon experiences in the WMO SWCEM, the JAXA has operated our homepage "JAXA Climate Rainfall Watch" since Mar. 2020, which shows the heavy rainfall/drought indices with the GUI.



https://sharaku.eorc.jaxa.jp/GSMaP_CLM/index.htm

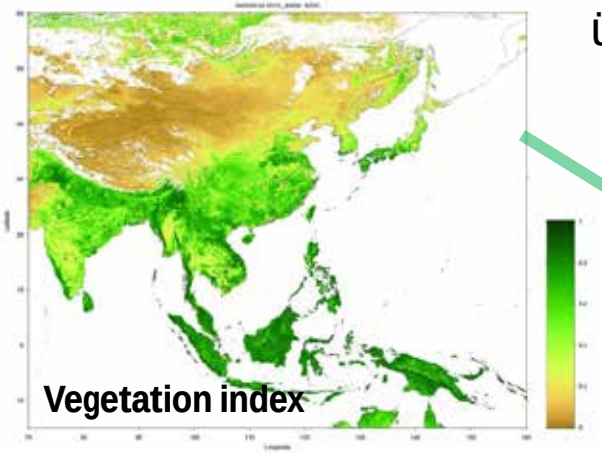
Earth Environment Monitoring by Optical Imager

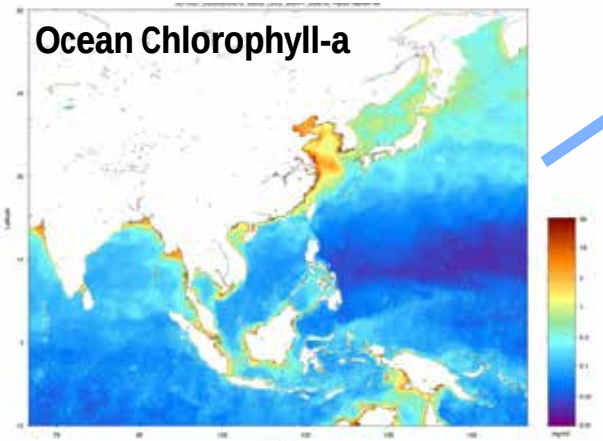


GCOM-C observation:

- ü Spatial distribution
- ü Seasonal change
- ü Year-to-year change
- ü …

Global ecosystem change





8-day mean during 24-31 Mar. 2020

ü Aerosol and cloud processes and radiative forcing

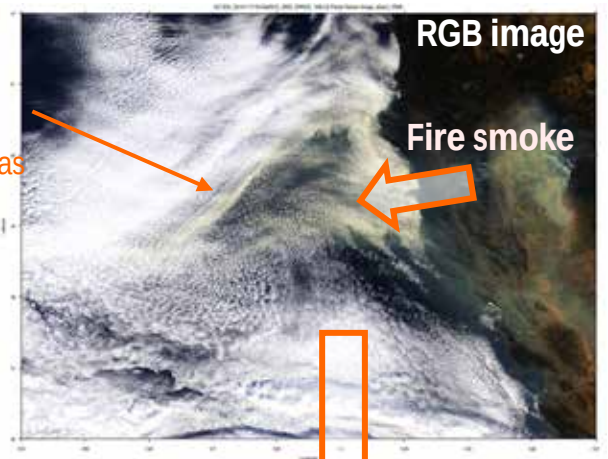
JAMSTEC, Tokyo Univ.

ü Model-Observation comparison
ü Correlation among variables
ü …

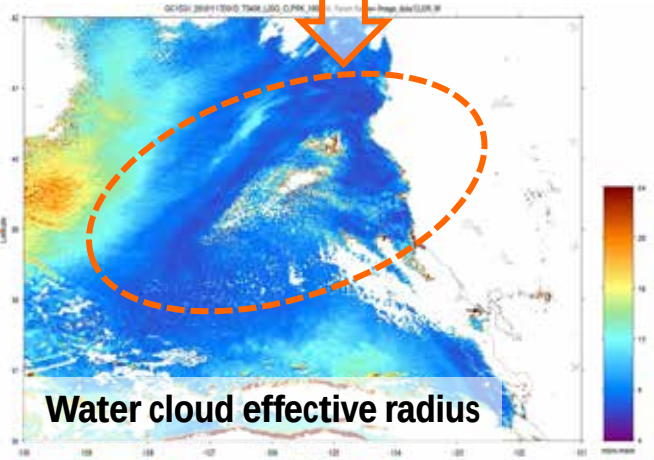
® **Improvement of the ESM**
® **Improvement of future prediction of the future global environment**

Aerosol and clouds by SGLI bands

The SGLI 380nm channel clearly shows aerosols (fire smoke) as brown color areas

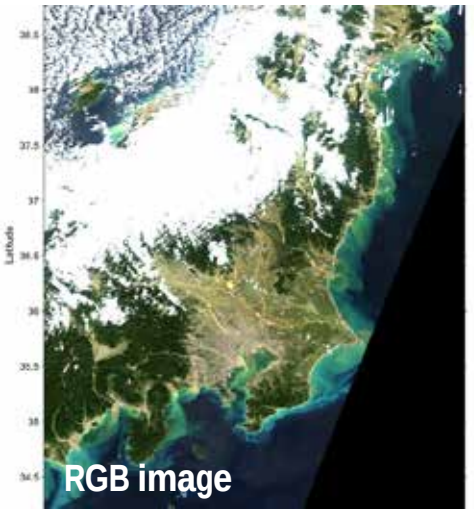


Cloud particle radius is affected by the aerosol

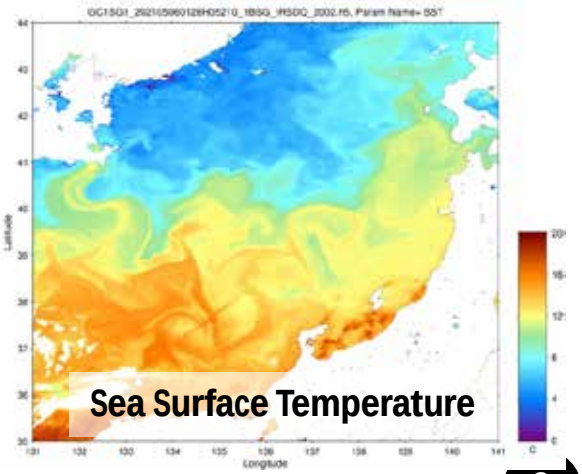


Offshore California on 17 Nov. 2018

Environmental monitoring by 250m



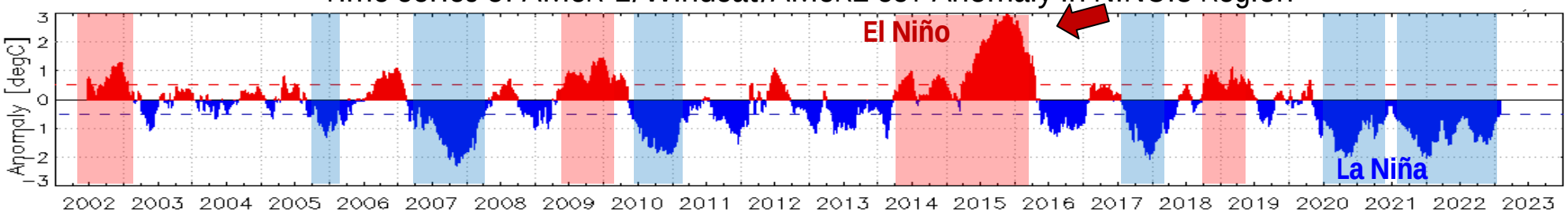
Total suspended matter



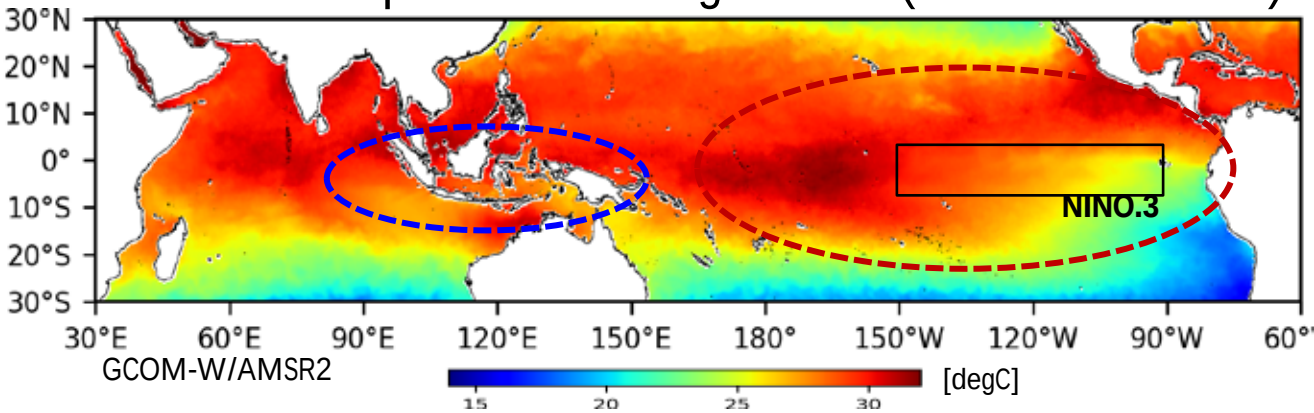
Around Japan Sea on 6 May. 2021

Monitoring of Large-scale Air-Sea Interactions

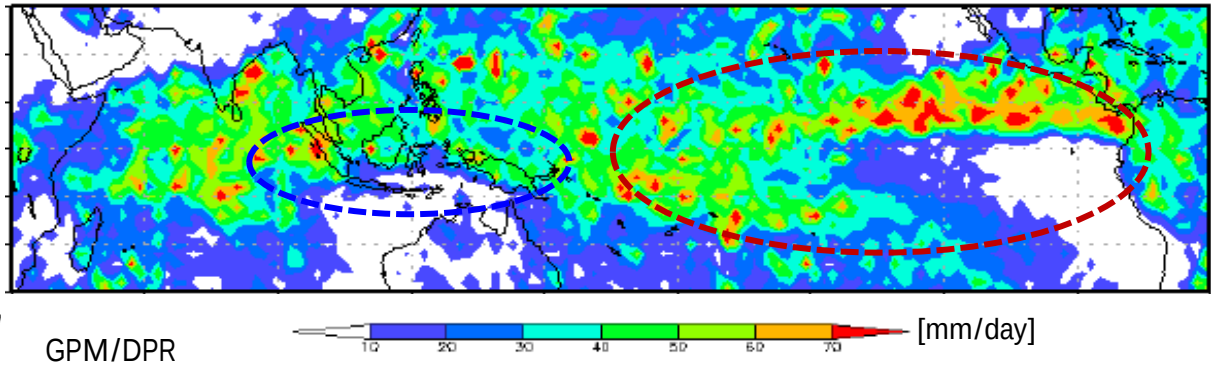
Time Series of AMSR-E/WindSat/AMSR2 SST Anomaly in NINO.3 Region



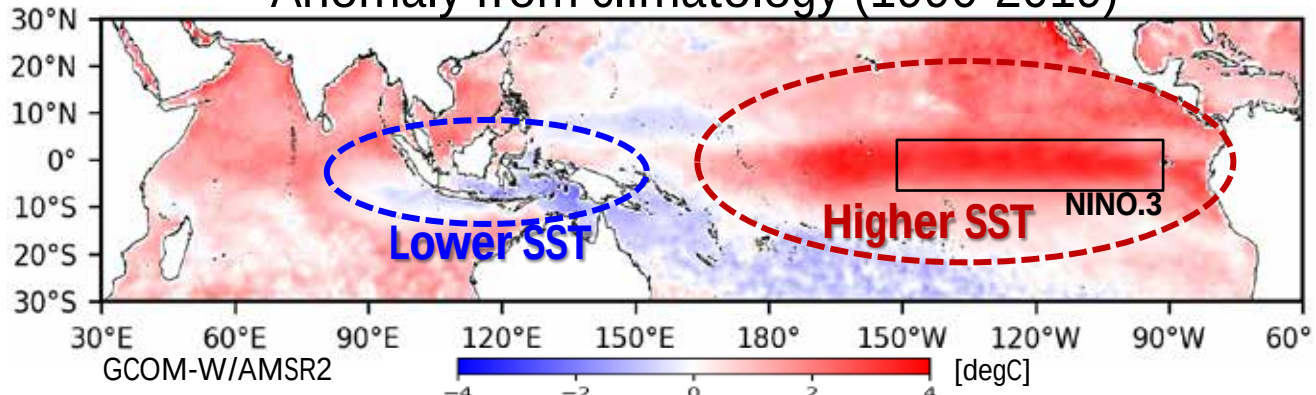
Sea Surface Temperature during El Niño (21-25 Nov. 2015)



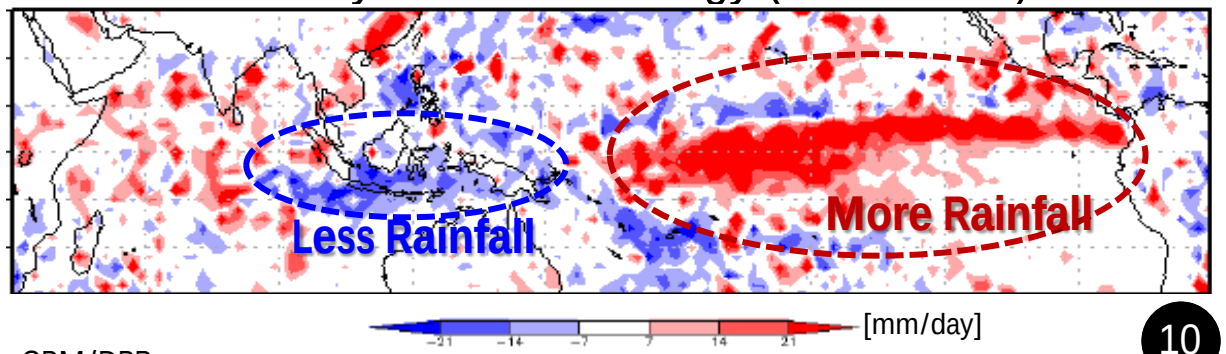
Surface Rainfall during El Niño (Oct. - Nov. 2015)



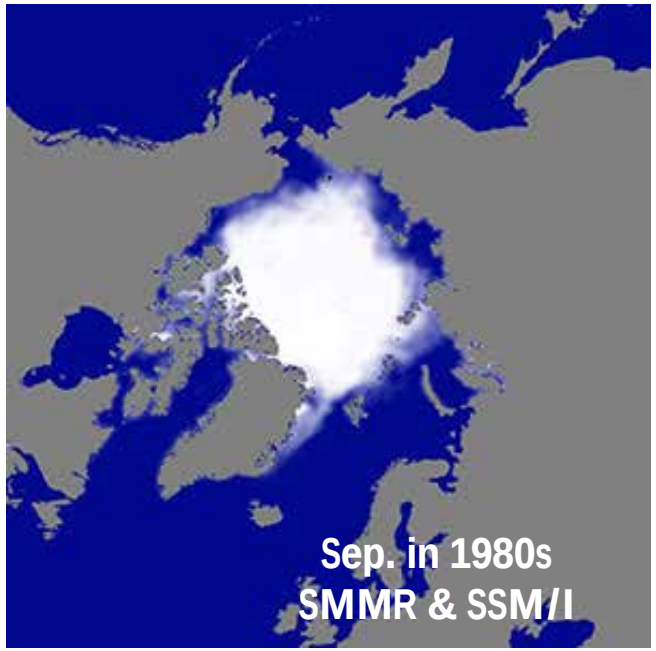
Anomaly from climatology (1990-2019)

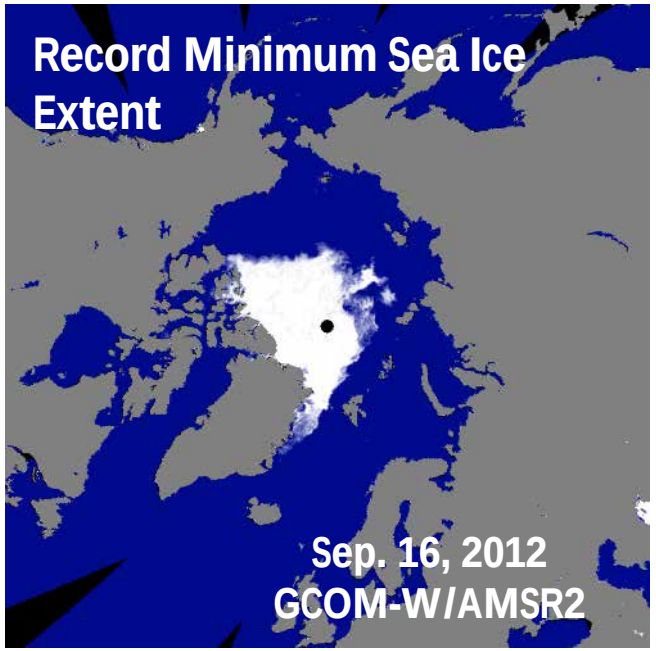


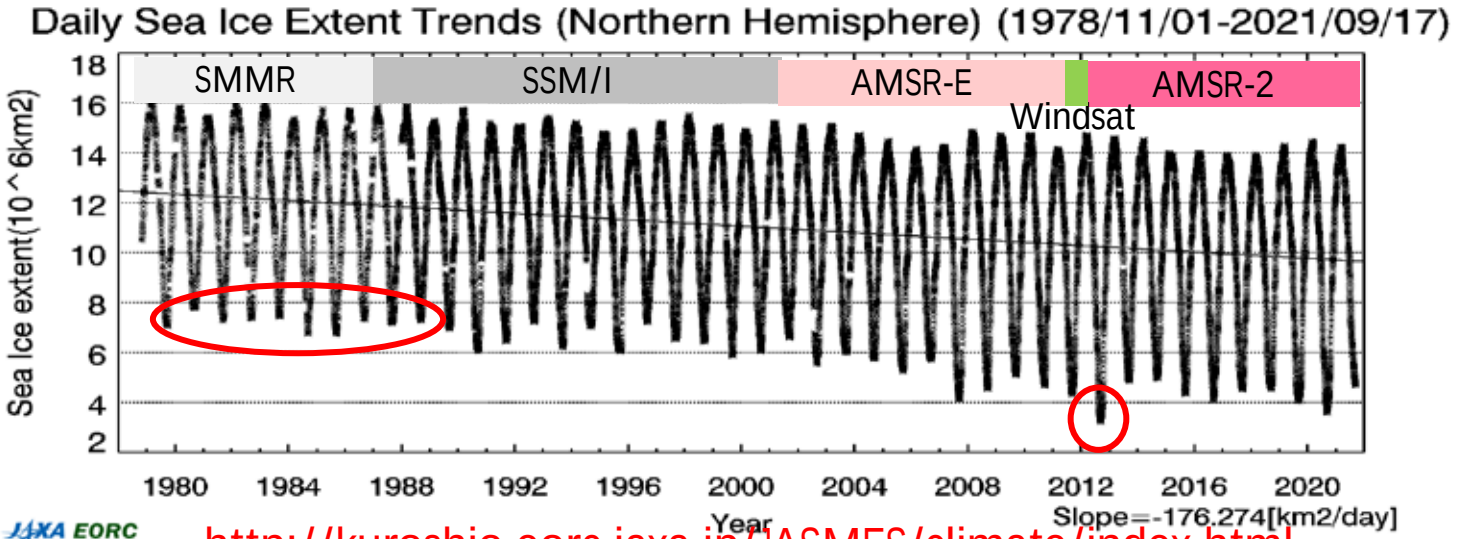
Anomaly from climatology (2014-2021)



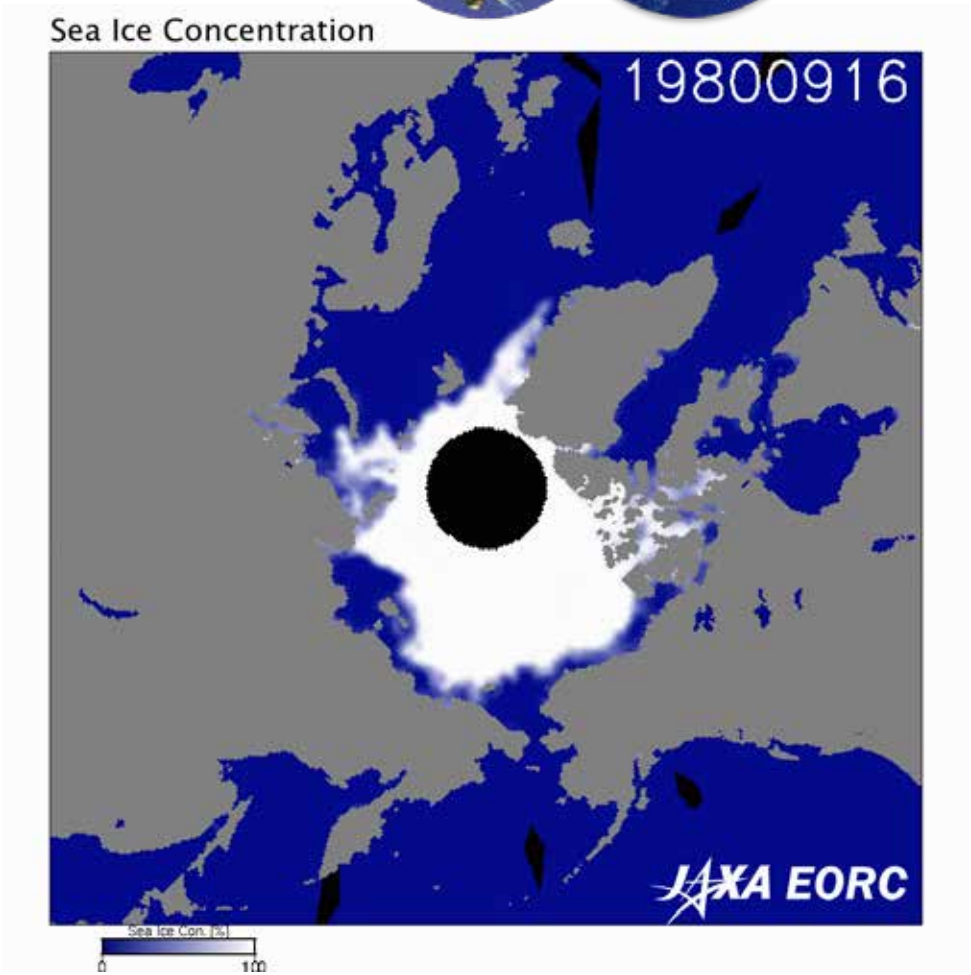
Monitoring Arctic Sea Ice by Passive Microwave Imagers







http://kuroshio.eorc.jaxa.jp/JASMES/climate/index.html



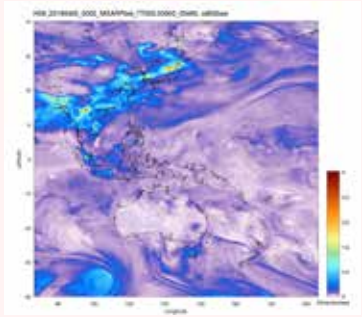
Variation of Arctic sea ice distribution on the day of Sep. 16 from 1980 to 2021, except 1982, 1985, 2002.

Satellite and Model Collaborations toward Earth Environment Predictions

JAXA 宇宙航空研究開発機構 Japan Aerospace Exploration Agency

Alert for Public Health

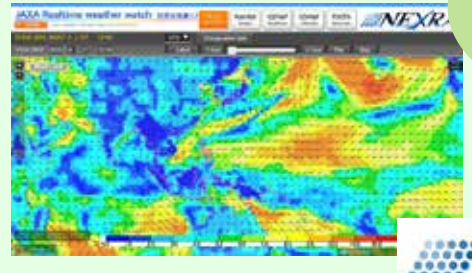
with JMA, MRI, NIES, Kyushu Univ.



Aerosol Model

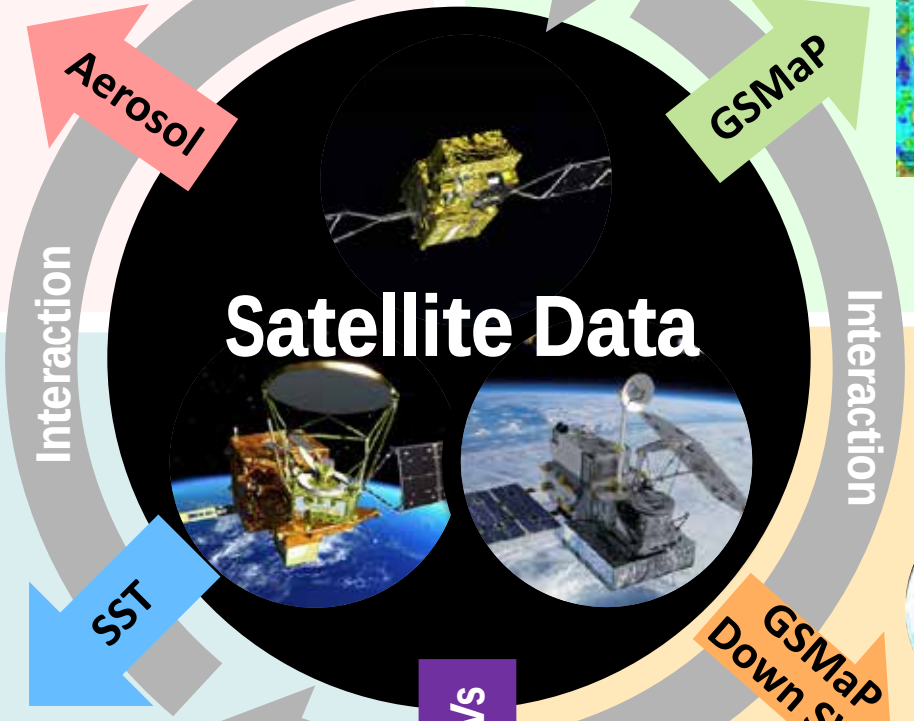
with U. Tokyo, RIKEN

Severe Weather Heavy Rainfall, Flood

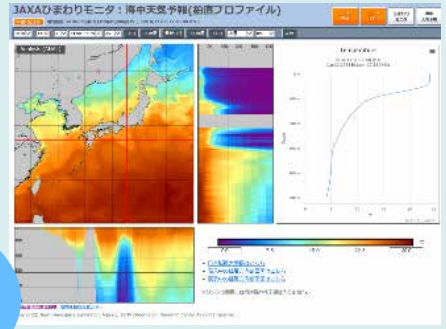


NEXRA

Atmospheric Model



Ocean Model

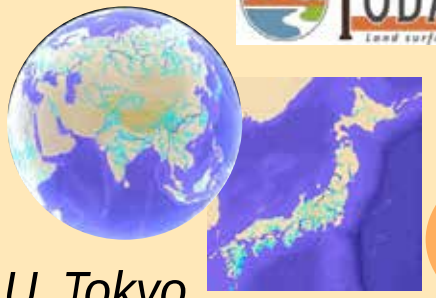


Fisheries, Ocean Transport, Climate

with JAMSTEC, RIKEN

Land/River Model

TODAY'S EARTH
Land surface simulation by JAXA and UTokyo



with U. Tokyo

Drought, Flood, Water-related Hazard

Climate Model & Earth System Model

[MEXT-Program] SENTAN

ArCS II Arctic Challenge for Sustainability II

with U. Tokyo, JAMSTEC, NIPR, etc.

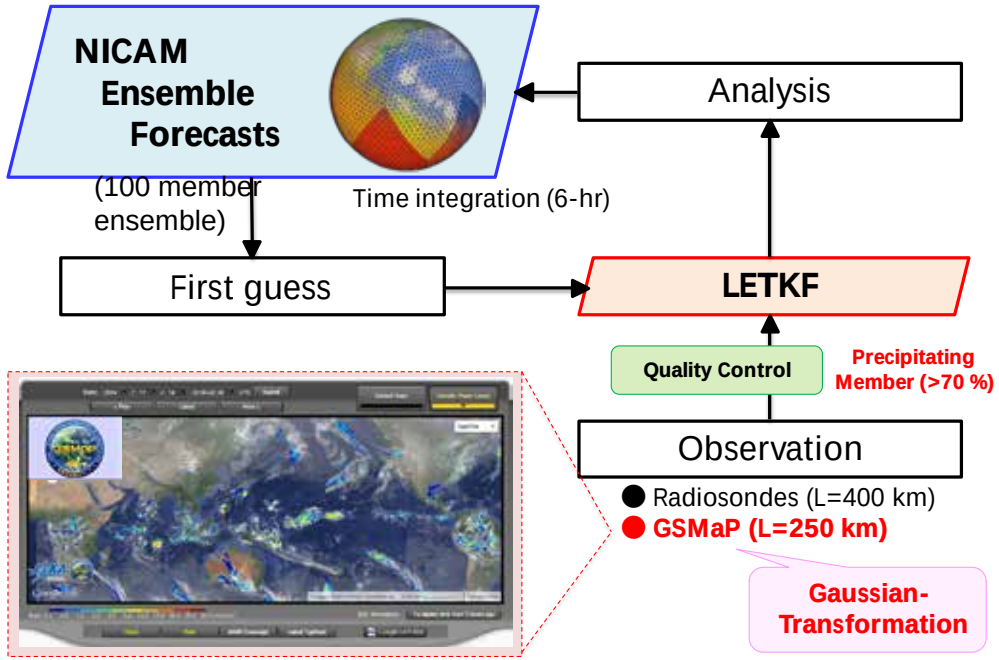
"JAXA Realtime Weather Watch" GSMaP Assimilation in JAXA Supercomputer System (NEXRA)

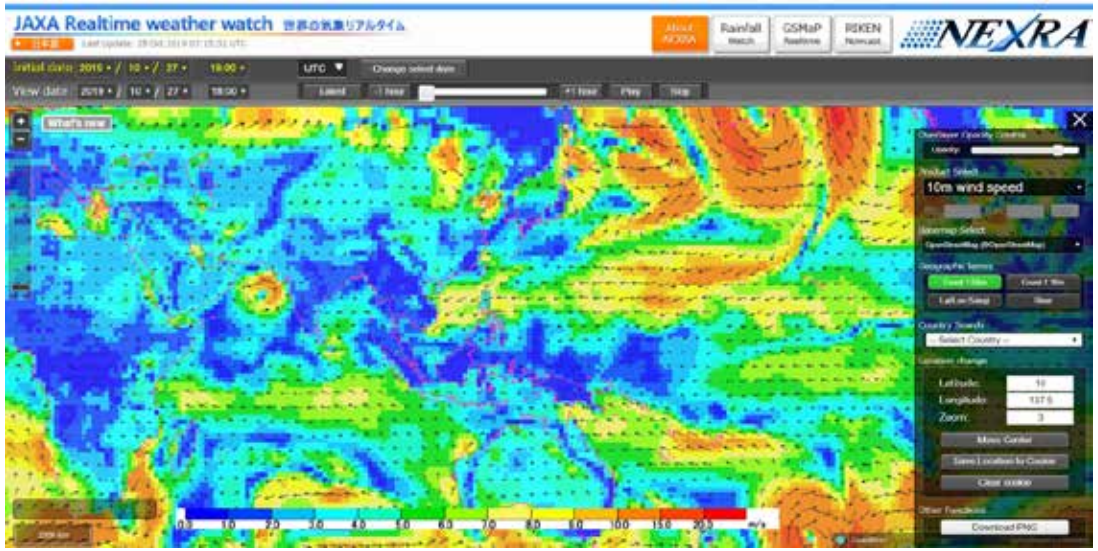
- JAXA, Univ. Tokyo and RIKEN installed the NICAM-LETKF data assimilation system using the GSMaP at JAXA supercomputer system generation 2 (JSS2) and has experimentally operated it in near-real time (Kotsuki et al. 2019, *SOLA*).

NICAM-LETKF at JAXA Research Analysis = NEXRA

14 km res.
Global scale

Assimilating GSMaP with NICAM-LETKF



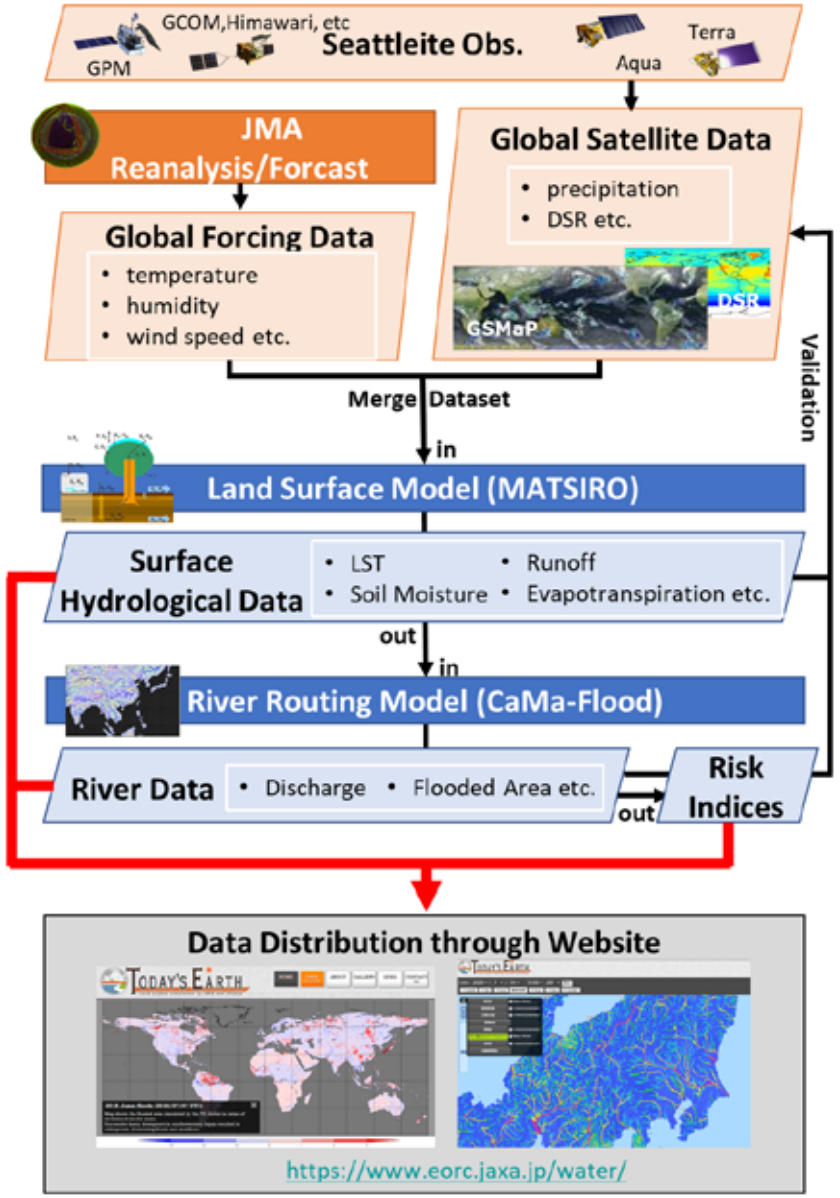


Monitoring home page of the NEXRA is now available as "**JAXA realtime weather watch**".

https://www.eorc.jaxa.jp/theme/NEXRA/

Kotsuki et al., 2019: Predictability of Record-Breaking Rainfall in Japan in July 2018: Ensemble Forecast Experiments with the Near-real-time Global Atmospheric Data Assimilation System NEXRA. *SOLA*, 15A, https://doi.org/10.2151/sola.15A-001.

Global Terrestrial Hydrological Simulation System; Today's Earth



- JAXA has developed the "Today's Earth", the satellite merged global terrestrial hydrological simulation system, under the joint research with the University of Tokyo.

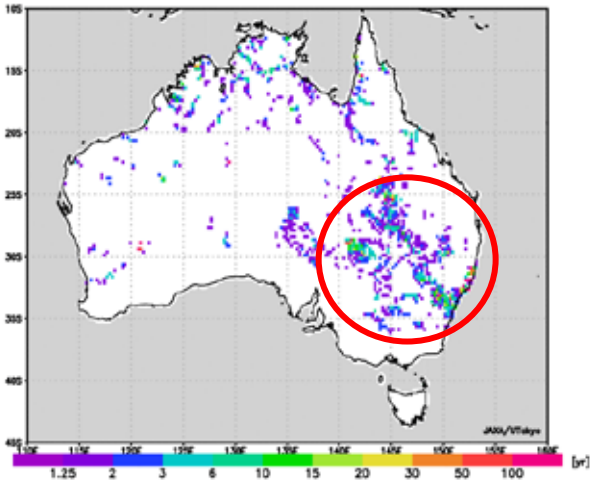
https://www.eorc.jaxa.jp/water/

	TE-Global (Global System)	TE-Japan (Regional System)
Horizontal resol. (lat/lon)	Land：0.5 deg., River：0.25 deg.	1/60 deg.
Temporal resol.	Every 3 hour	Every hour
Latency	About 3 days	**Real-time** *forecast data distribution is limited within research purpose due to the Japanese law
Satellite data used in the System (in prep.)	GSMaP, Terra/Aqua MODIS, SRTM30, NOAA AVHRR, (AW3D, GCOM-C)	SRTM30, NOAA AVHRR, (GSMaP, Himawari-8, ALOS HRLC)
Product	River discharge, Flooded area, Soil moisture, Snow amount, Latent heat flux, etc.	

- Today's Earth can visualize risk indices in terms of return period as well as various hydrological products.

Example of flood risk estimation by TE-Global in the case of the sever flood in New South Wales, Australia, March 2021

https://edition.cnn.com/2021/03/21/australia/australia-flood-natural-disaster-intl-hnk/index.html

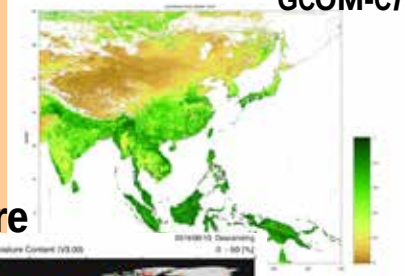


Satellite Data for Improving Climate Change Studies

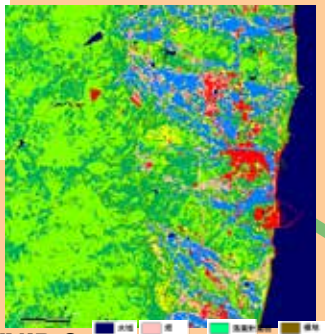
LAND

Vegetation Index

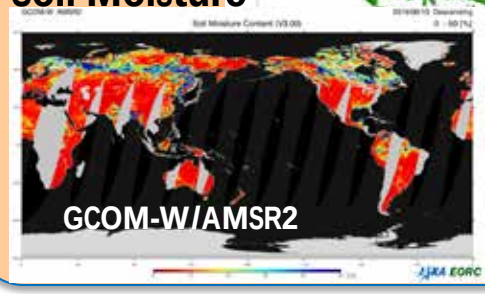
GCOM-C/SGLI



Land Cover



Soil Moisture



ALOS/AVNIR-2

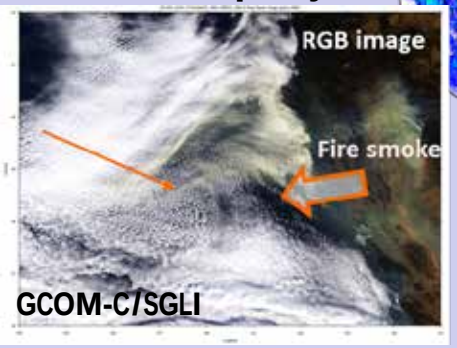
ü Comparison of model & observation
ü Correlation between parameters
ü …

® **Improvement of ESM**
® **Improvement of future prediction of Earth environment**

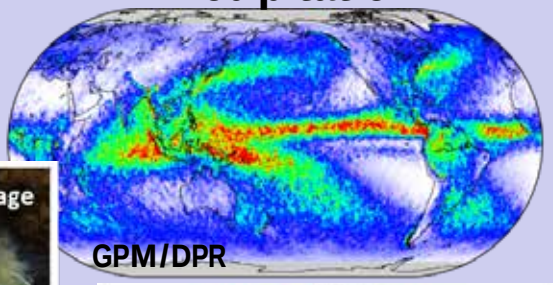
[MEXT-Program] SENTAN

ATMOSPHERE

Aerosol Property

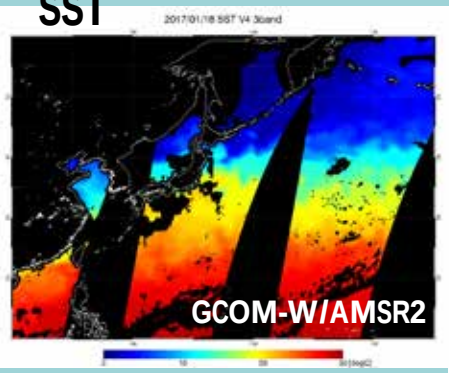


Precipitation

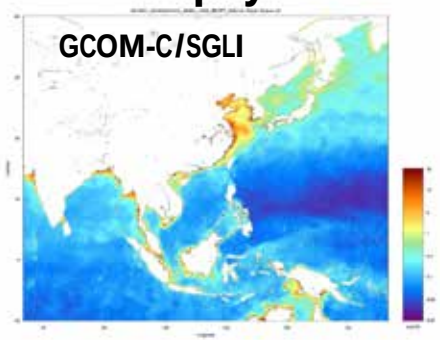


OCEAN

SST

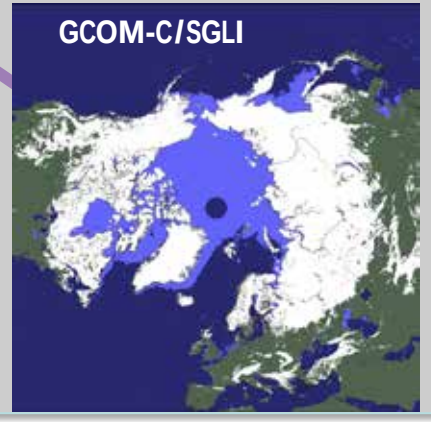


Chlorophyll-a

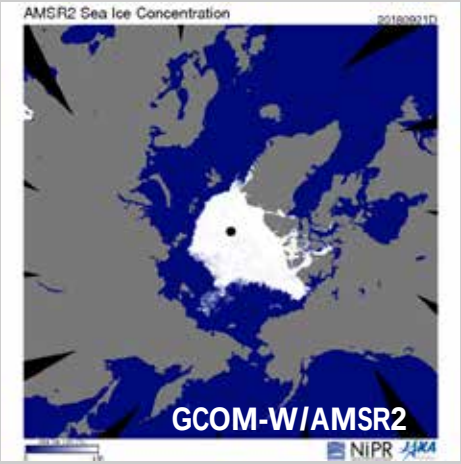


CRYOSPHERE

Snow & Ice Map



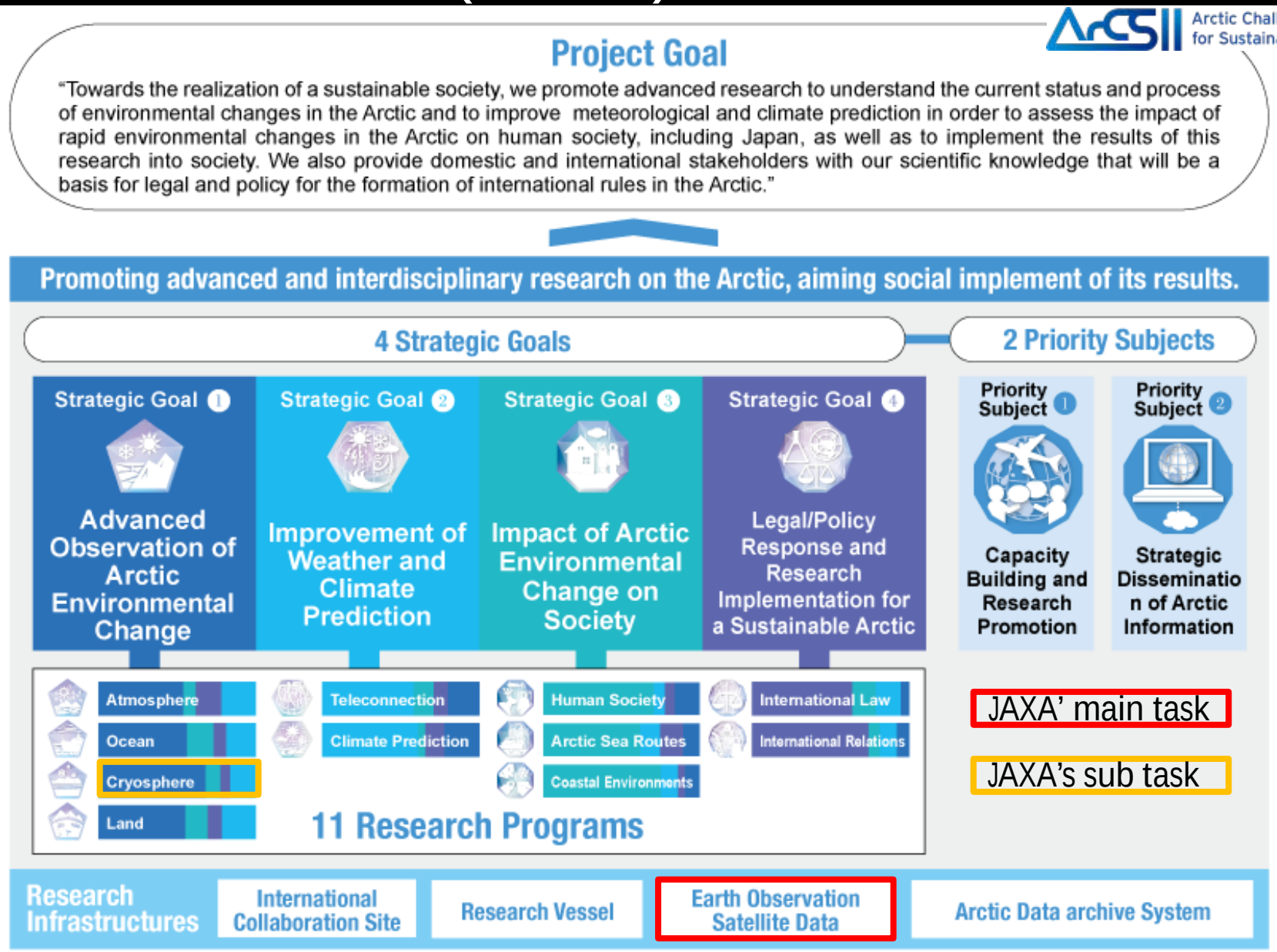
Sea Ice Concentration



Natural Disasters	Agriculture
Water Resources	Fisheries
Ecosystem	Health

MEXT Project for the Advanced Studies on the Arctic (ArCSII)

- "ArCSII" is a 5-year project for the advanced and interdisciplinary research on the Arctic, led by the National Institute of Polar Studies (NIPR), and funded by Ministry of Education, Culture, Sports, Science and Technology - Japan (MEXT) from Jun. 2000 to Mar. 2025, succeeding previous "ArCS" project
- JAXA leads one of four research infrastructures to provide the Earth observation satellite data, including GCOM-W, GCOM-C, and ALOS-2, to ArCSII research programs and support data utilization in their researches.



MEXT-Program for the Advanced Studies of Climate Change Projection (SENTAN)

- SENTAN is a 5-year program for climate change studies funded by MEXT from Jun. 2022 to Mar. 2027, succeeding previous “TOUGOU” program
- JAXA collaborates with both TOUGOU and SENTAN to utilize satellite-based data in their activities.

Area 1: Predictive understanding of Earth system changes based on physical evidence

PI: Prof. Masahiro Watanabe, the University of Tokyo

- **Advanced studies for global climate simulations**
- **Attributing and Predicting Earth System Variability**

Area 2: Biogeochemical modeling and climate simulations for carbon budget assessment

PI: Dr. Michio Kawamiya, JAMSTEC

- **A hierarchical approach to advancing Earth system modeling**
- **Development of an integrated framework for Earth system research**
- **Earth-human system interaction and future scenario analysis**
- **Technical and clerical support for inter-theme cooperation**

Area 3: Increasing the sophistication of climate change projections around Japan

PI: Dr. Izuru Takayabu, Japan Meteorological Business Support Center

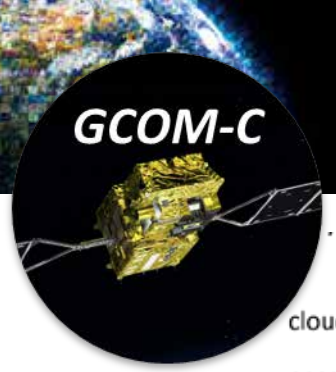
- **Development of projection system and analysis of mechanism for climate change around Japan**
- **Creating climate change projection information and elucidating extreme event mechanisms for promoting regional and basin scale adaptation measures**
- **Creation of high-accuracy climate projection datasets for vulnerable regions in the world**

Area 4: Development of an integrated hazard projection model

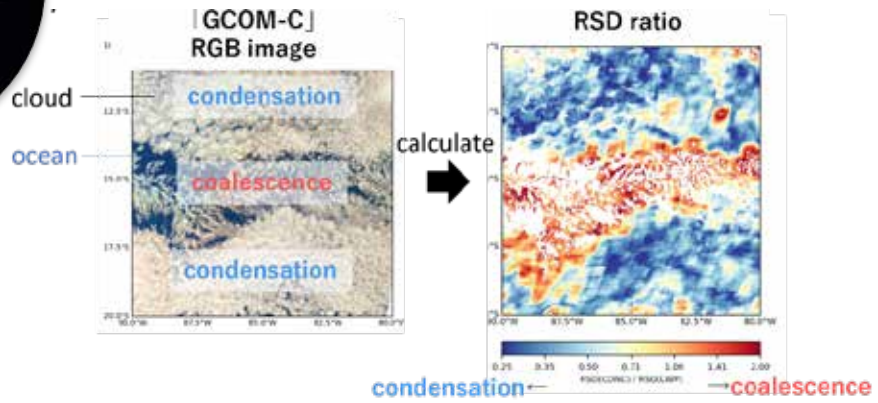
PI: Prof. Nobuhito Mori, Kyoto University

- **Integrated hazard modelling and nationwide future projections**
- **Elaborate hazard model development and hazard mechanism elucidation**
- **Quantification of climate change factors in extreme hazards**
- **International cooperation for hazard and risk assessments in the Asia-Pacific region**
- **Flexible adaptation strategies to the future changes in hazard and society**

Satellite-Climate Model Collaboration Example:
Research to improve cloud growth process by using GCOM-C/SGLI

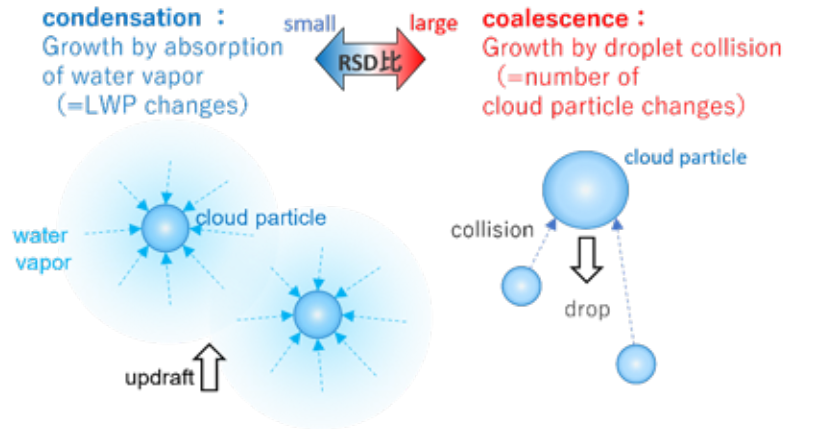


[MEXT-Program] SENTAN



$$RSD\ ratio = \frac{RSD[Nc]}{RSD[LWP]}$$

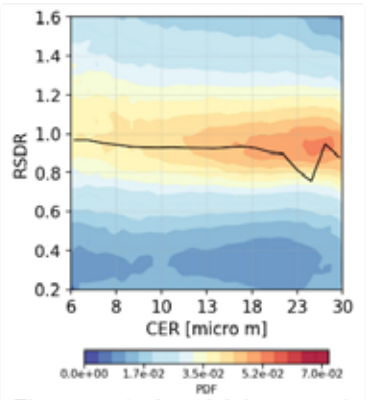
RSD ratio represents the dominance of the condensation or coalescence in cloud droplet growth



Successfully quantified the cloud grain growth process by analyzing the horizontal structure of clouds using cloud microphysical property products (cloud grain size and cloud optical thickness) at 250 m resolution.

- **BACKGROUND**: Uncertainties abound in the setup of cloud microphysical processes (related to cloud particle growth and the formation of raindrops and ice crystals) in numerical models.
- **RESULTS**: Successful **quantitative evaluation of cloud grain growth processes** through horizontal structure analysis of cloud microphysical characteristics (cloud grain size and cloud optical thickness) utilizing the 250m resolution of SGLI. It was shown that **SGLI can observe features of the cloud growth process that have not been reproduced by models.**
- **FUTURE PLAN**: Improve the climate models by multivariate composite analysis with the polarization channels and multiple wavelengths in "SENTAN" program.

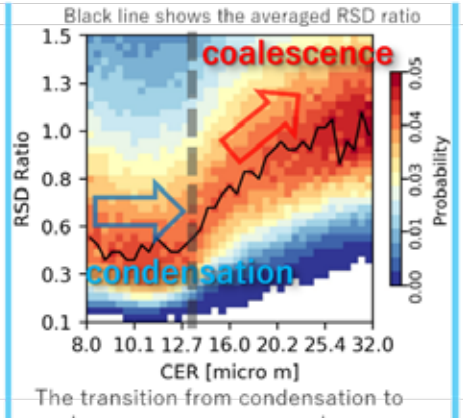
RSD vs. CER(cloud particle radius) calculated by numerical model(NICAM)



The numerical model does not show the difference of cloud microphysical process.

Compare & improve

RSD vs. CER(cloud particle radius) calculated by GCOM-C/SGLI



The transition from condensation to coalescence process around CER=13 μm is detected by GCOM-C satellite observation.

Nagao, T. M., & Suzuki, K.. 2020, GRL

Satellite-Climate Model Collaboration Example:
Fire Modeling by using Satellite Data

[MEXT-Program] SENTAN

■Plan under JAXA-SENTAN collaboration

- By setting various parameters related to the combustion environment, burned area, and material release in the fire model based on the observation results of SGLI, etc., an Earth system model reflecting the effects of fire (contribution to material circulation and radiation budget) will be constructed, aiming to improve the prediction accuracy of climate change.

SENTAN Program Objective: To improve the accuracy of climate change prediction by upgrading Earth system models

- **Area 2:** Biogeochemical modeling and climate simulations for carbon budget assessment
  - **Improvement of models for fire-related processes**
  - Marine ecosystems
  - Terrestrial vegetation
  - ...

Input to the model through JAXA's product development and analysis studies

input

Background data

- SGLI ・**LST**
- SGLI ・**ET**
- SGLI ・**AGB**
- SGLI ・**NDVI**
- SGLI ・**LULC**
- SGLI ・**Solar radiation**
- SGLI ・**Ice cloud (lightning)**
- GSMaP ・Precipitation
- GSMaP ・SPI
- Today's Earth ・Temp, Moist, Wind

output

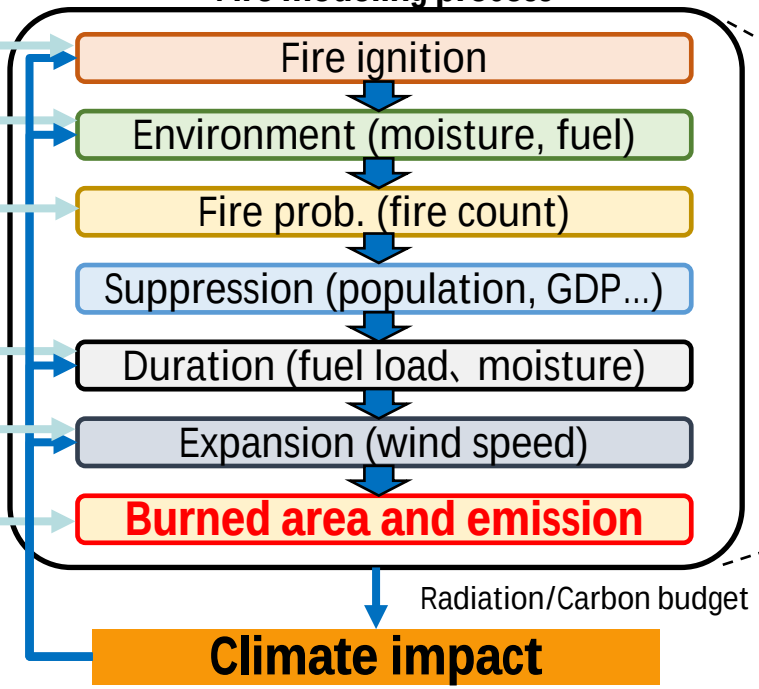
Burned area

- SGLI ・**NDVI**・**LULC changes**
- SGLI ・Albedo changes

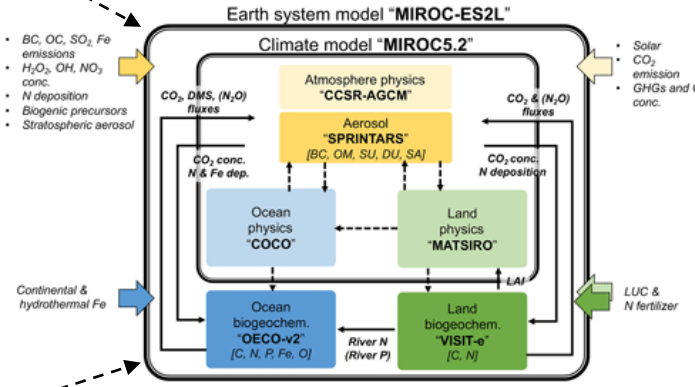
Emission

- SGLI ・**Aerosols**
- E-CARE
- GOSAT ・CO_2、CH_4、water vapor..

Fire modeling process



(Modified from figure in Rabin et al. 2017)



(Hajima et al. 2020)

To improve the coupling process between subsystems

Summary

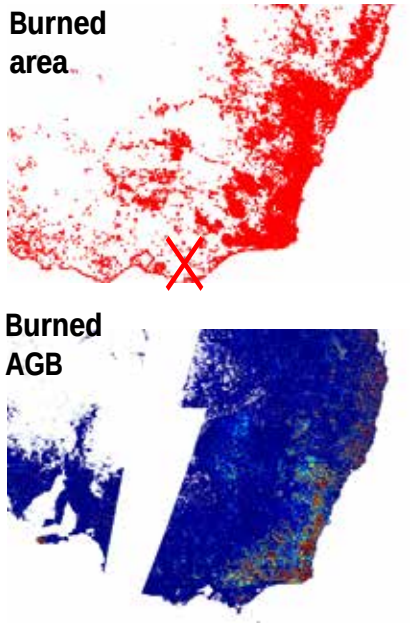
- Climate Change and Roles of Earth Observing Satellites
  - Monitoring of climate change and essential climate variables
  - Reducing large uncertainties in the future prediction of climate
  - Evaluation of numerical simulations and improvement of models
- JAXA's Satellites
  - Climate change and water cycle: GCOM-C, GCOM-W, GPM, EarthCARE (JFY2023), GOSAT-GW (JFY2024)
  - Greenhouse gases: GOSAT, GOSAT-2, GOSAT-GW (JFY2024)
  - Natural Disasters: ALOS-2, ALOS-3 (JFY2022), ALOS-4 (JFY2023)
- Collaboration and Combined Analysis with Numerical Models
  - GSMaP: Multi-satellite precipitation product from a blended Passive Microwave radiometer(PMW)-IR algorithm
  - NEXRA: GSMaP assimilated atmospheric model with high spatial resolution
  - Today's Earth : Global & regional terrestrial hydrological simulation system
  - Air Pollution : Aerosol assimilation for weather and alert for public health
  - Ocean : SST data assimilation for climate, weather, fishery
  - ArCSII: Various satellite data for the advanced and interdisciplinary research on the Arctic
  - SENTAN: Various satellite data for Earth System Model to improve future prediction
  - Collaborations with WMO, JMA and other agency/institution/private companies

backup

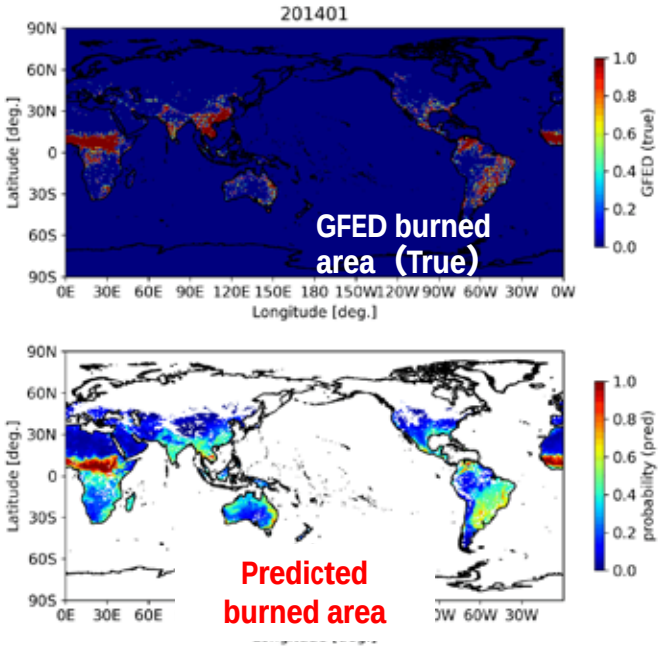
Satellite-Climate Model Collaboration Example:
Fire Modeling by using GCOM-C/SGLI

[MEXT-Program] SENTAN

- ü **BACKGROUND**: According to IPCC AR6, the contribution of **wildfires have not yet been fully considered in Earth system models**.
- ü **RESULT**: Based on the discussions in "TOUGOU" program, started collaboration with **JAMSTEC** on **fire modeling** by taking advantage of **SGLI, a multi-wavelength optical sensor capable of comprehensive observation from fire occurrence to disturbance and climate effects** (burned area, carbon emission, aerosol radiative forcing, etc.).
- ü **FUTURE PLAN**: Newly participated in **"SENTAN"** program (FY2022-) to improve Earth system model through **fire process** modeling studies based on SGLI observations.

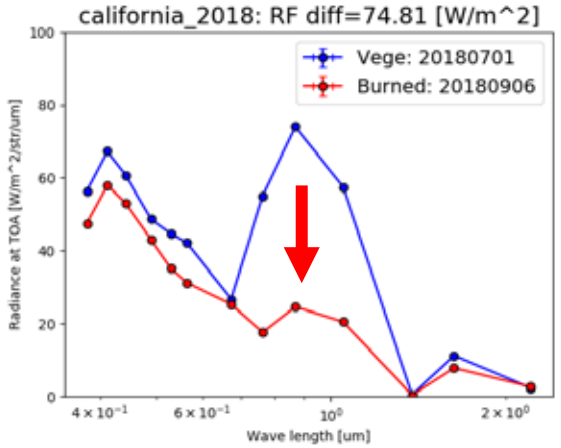


Estimation of carbon release using burned area (NDVI) and amount of biomass burned (AGB)

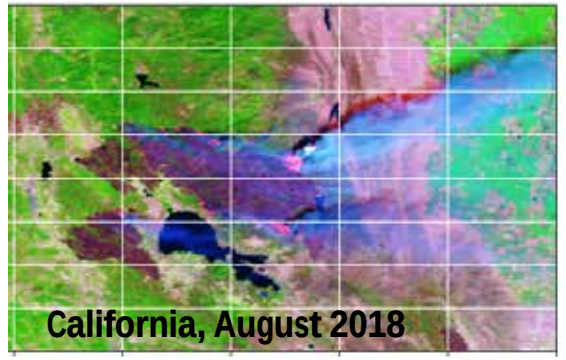


Prototype fire occurrence prediction model using SGLI physics

Radiance change with land cover change before and after fire



Radiance spectra before and after fire @TOA



- ü Improving the accuracy of vegetation regeneration models by monitoring post-burn cover changes.
- ü Estimation of the effect of global land cover change on radiative forcing.
  →Feedback to the model.

A collaborative framework with "SENTAN" program has been established through research results on cloud growth and fire generation processes that take advantage of the features of SGLI. In the future, we aim to contribute to the IPCC through the advancement of climate and earth system models based on observations.