# Facilitating Exploitation of International LEO/GEO Meteorological Satellite Observing Systems Through Community Satellite Processing Package (CSPP)

*Allen Huang, Liam Gumley, Kathy Strabala, and Graeme Martin*
Space Science and Engineering Center (SSEC)
Cooperative Institute for Meteorological Studies (CIMSS)
University of Wisconsin-Madison, Madison (UW-Madison) USA
and
*Mitch Goldberg*
National Environmental Satellite, Data, and Information Service (NESDIS)
National Oceanic and Atmospheric Administration (NOAA), USA

**AOSMUC-12**
**Tokyo, Japan (Virtual)**
**11-18 November 2022**

# Community Satellite Processing Package (CSPP)



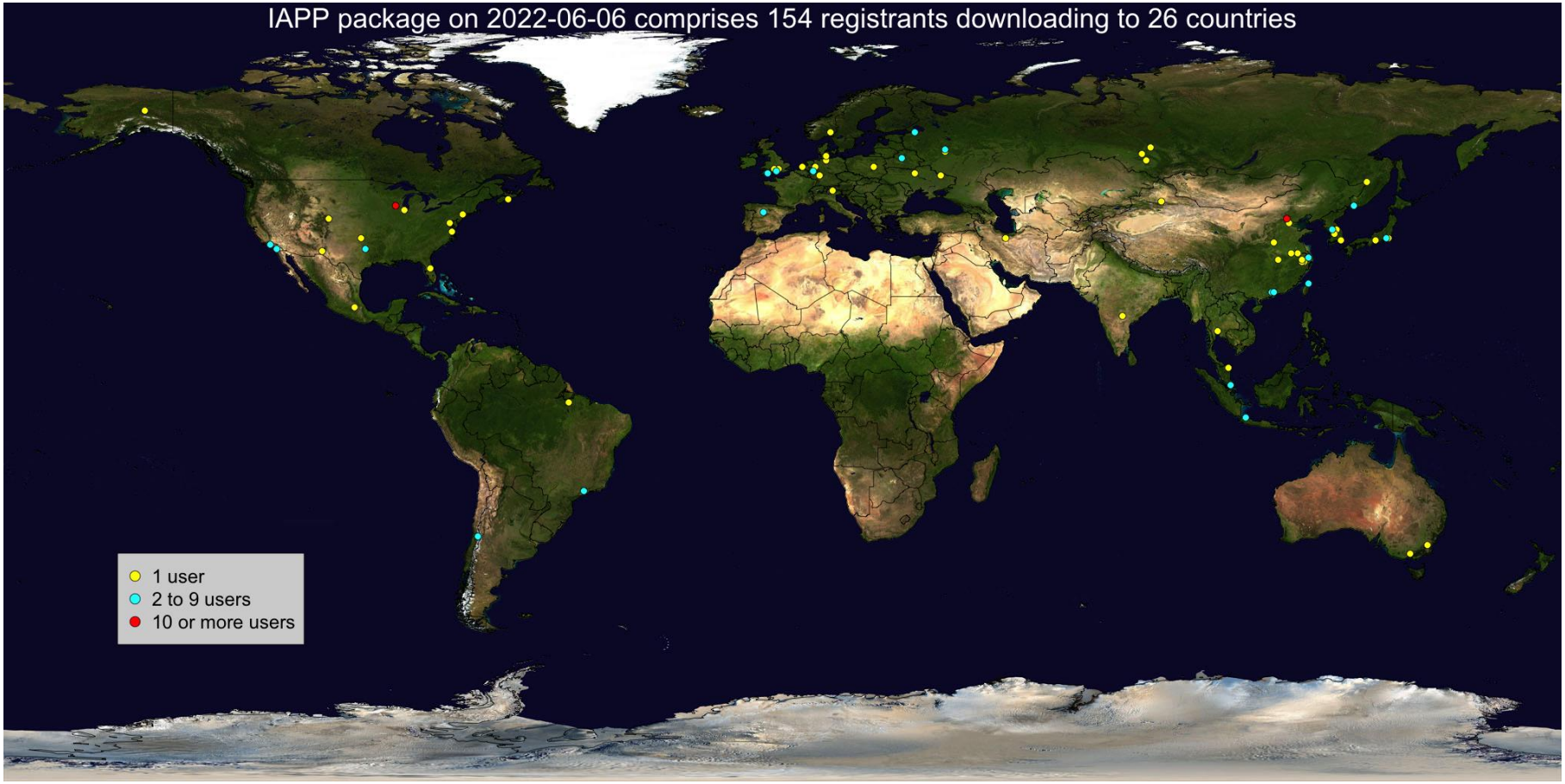



http://cimss.ssec.wisc.edu/cspp/

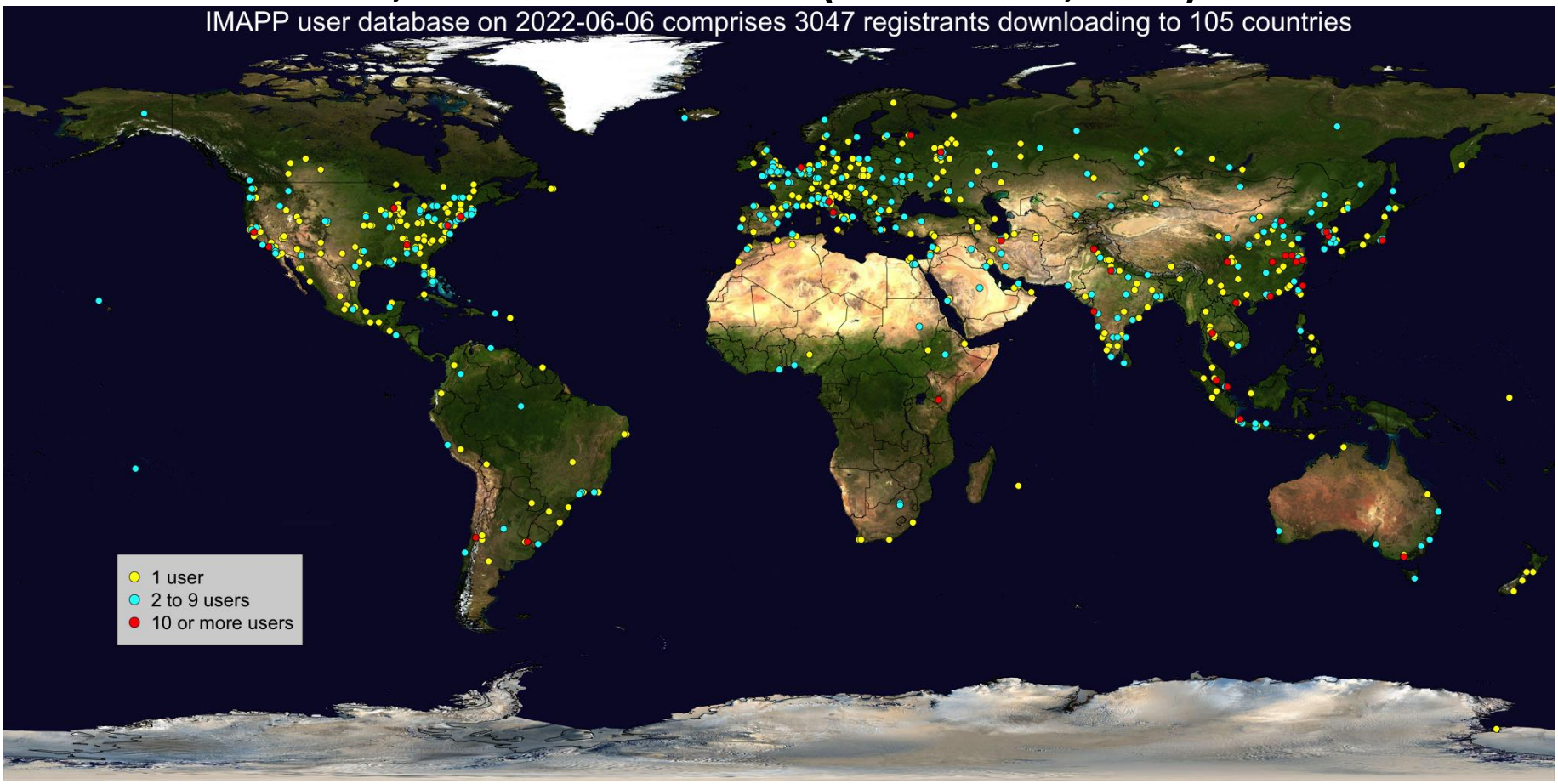
# 40 *years (1982-2022) Sharing of Meteorological Satellite Data Processing S/W*

- 1982: TOVS export package – ITPP
  - Father of processing package – Prof. William L. Smith
  - 1st NOAA infrared/microwave sounding retrieval S/W for global users (HIRS/MSU)
- 1999: International ATOVS Processing Package (IAPP)
  - 2nd generation of NOAA sounding retrieval package (HIRS-2/AMSU)
- 2000: International MODIS/AIRS Processing Package (IMAPP)
  - 1st NASA hyperspectral sounding and imaging processing package (AIRS/AMSU/MODIS)
- 2012-2022: Community Satellite Processing Package (CSPP)
  - 1st NOAA JPSS program critical processing package to include multi-satellites and multi-sensors (VIIRS/CrIS/ATMS/IASI/MERSI/ABI/AHI/AVHRR….)

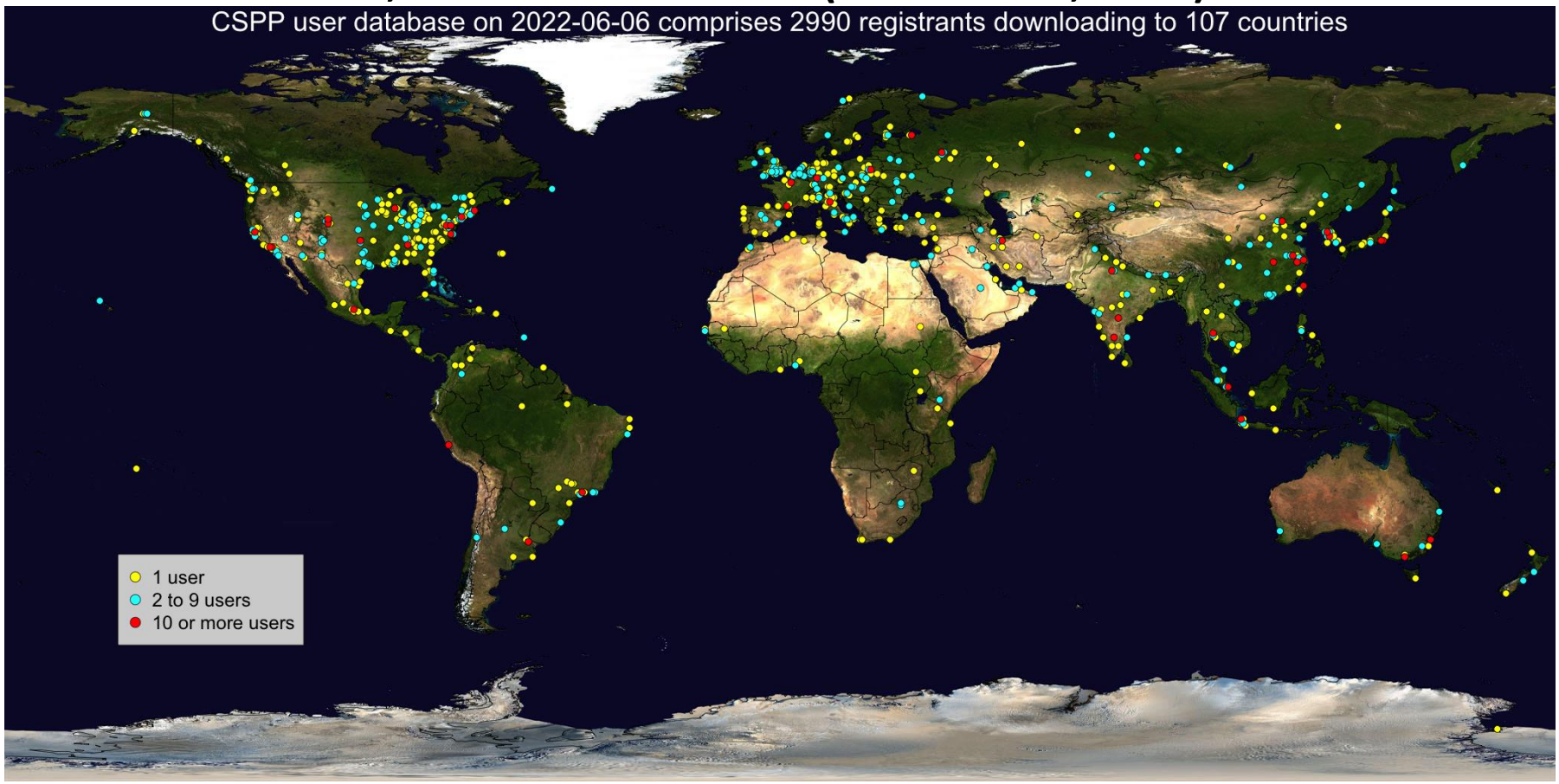
# IAPP World-wide users:
# 154 in 26 Countries (as of June 6, 2022)



# IMAPP World-wide users:
# 3,047 in 105 Countries (as of June 6, 2022)



# CSPP LEO World-wide users:
# 2,990 in 107 Countries (as of June 6, 2022)



# CSPP

**CSPP S/W Product Packages:**

- Clouds - $CLAVR_X$
- Profiles & Trace Gases: NUCAPS
- Profiles: HSRTV
- Profiles & Clouds: MIRS
- SST: ACSPO
- Flood Detection: Flood
- Active Fire: Fire
- ATOVS: IAPP
- Clouds & Profile: GeoAIT/GRB/GVAR
- Imagery clouds, aerosol & LST - AITF
- Clouds, Fog - GEOCAT

**SATELLITES:**

- S-NPP
- NOAA-20
- TERRA/AQUA
- METOP-A/-B
- FY-3C/3D
- GOES-15/16/17
- HIMAWARI

**SDR/LEV 1**
**Preprocessing:**
**Calibration/NAVIGATION**

**SENSORS:**

- AVHRR
- VIIRS
- MODIS
- AIRS/AMSU
- ATMS
- CrIS
- IASI
- MERSI
- ABI & GLM
- AHI

**EDR/LEV 2**
**Atmospheric/Land/Oceanic PRODUCTS**

**PRODUCTS:**

- RGB images
- Clouds
- Profiles
- Trace gases
- LST/SST
- Aerosol/Dust
- Fire
- Flood
- Others

**IDR/LEV 3**
**Applications**

Applications:

- Weather forecast
- Fire & Flood
- Air Quality
- Aviation Safety
- Severe Storm

**CSPP S/W Tool Packages:**

- Map Projection --Polar2Grid & Geo2Grid
- Visualization – HYDRA & RealEarth

https://cimss.ssec.wisc.edu/cspp/ & https://cimss.ssec.wisc.edu/csppgeo

# CSPP

**CSPP S/W Product Packages:**

- Clouds - CLAVR$_X$
- Profiles & Trace Gases: NUCAPS
- Profiles: HSRTV
- Profiles & Clouds: MIRS
- SST: ACSPO
- Flood Detection: Flood
- Active Fire: Fire
- ATOVS: IAPP
- Clouds & Profile: GeoAIT/GRB/GVAR
- Imagery clouds, aerosol & LST - AITF
- Clouds, Fog - GEOCAT

**SATELLITES:**

- S-NPP
- NOAA-20
- TERRA/AQUA
- METOP-A/-B
- FY-3C/3D
- GOES-15/16/17
- HIMAWARI

**SDR/LEV 1**
**Preprocessing:**
**Calibration/NAVIGATION**

**EDR/LEV 2**
**Atmospheric/Land/Oceanic PRODUCTS**

**IDR/LEV 3**
**Applications**

**CSPP S/W Tool Packages:**

- Map Projection --Polar2Grid & Geo2Grid
- Visualization – HYDRA & RealEarth

**SENSORS:**

- AVHRR
- VIIRS
- MODIS
- AIRS/AMSU
- ATMS
- CrIS
- IASI
- MERSI
- ABI & GLM
- AHI

**PRODUCTS:**

- RGB images
- Clouds
- Profiles
- Trace gases
- LST/SST
- Aerosol/Dust
- Fire
- Flood
- Others

**Applications:**

- Weather forecast
- Fire & Flood
- Air Quality
- Aviation Safety
- Severe Storm

https://cimss.ssec.wisc.edu/cspp/ & https://cimss.ssec.wisc.edu/csppgeo

# CSPP

**CSPP S/W Product Packages:**

- Clouds - CLAVR$_X$
- Profiles & Trace Gases: NUCAPS
- Profiles: HSRTV
- Profiles & Clouds: MIRS
- SST: ACSPO
- Flood Detection: Flood
- Active Fire: Fire
- ATOVS: IAPP
- Clouds & Profile: GeoAIT/GRB/GVAR
- Imagery clouds, aerosol & LST - AITF
- Clouds, Fog - GEOCAT

**SATELLITES:**

- S-NPP
- NOAA-20
- TERRA/AQUA
- METOP-A/-B
- FY-3C/3D
- GOES-15/16/17
- HIMAWARI

**SDR/LEV 1**
**Preprocessing:**
**Calibration/NAVIGATION**

**SENSORS:**

- AVHRR
- VIIRS
- MODIS
- AIRS/AMSU
- ATMS
- CrIS
- IASI
- MERSI
- ABI & GLM
- AHI

**EDR/LEV 2**
**Atmospheric/Land/Oceanic PRODUCTS**

**PRODUCTS:**

- RGB images
- Clouds
- Profiles
- Trace gases
- LST/SST
- Aerosol/Dust
- Fire
- Flood
- Others

**IDR/LEV 3**
**Applications**

Applications:

- Weather forecast
- Fire & Flood
- Air Quality
- Aviation Safety
- Severe Storm

https://cimss.ssec.wisc.edu/cspp/ & https://cimss.ssec.wisc.edu/csppgeo

# CSPP

**SATELLITES:**
- S-NPP
- NOAA-20
- TERRA/AQUA
- METOP-A/-B
- FY-3C/3D
- GOES-15/16/17
- HIMAWARI

**SDR/LEV 1**
**Preprocessing:**
**Calibration/NAVIGATION**

**SENSORS:**
- AVHRR
- VIIRS
- MODIS
- AIRS/AMSU
- ATMS
- CrIS
- IASI
- MERSI
- ABI & GLM
- AHI

**EDR/LEV 2**
**Atmospheric/Land/Oceanic PRODUCTS**

**PRODUCTS:**
- RGB images
- Clouds
- Profiles
- Trace gases
- LST/SST
- Aerosol/Dust
- Fire
- Flood
- Others

**IDR/LEV 3**
**Applications**

Applications:
- Weather forecast
- Fire & Flood
- Air Quality
- Aviation Safety
- Severe Storm

https://cimss.ssec.wisc.edu/cspp/ & https://cimss.ssec.wisc.edu/csppgeo

# CSPP

**SATELLITES:**
- S-NPP
- NOAA-20
- TERRA/AQUA
- METOP-A/-B
- FY-3C/3D
- GOES-15/16/17
- HIMAWARI

**SDR/LEV 1**
**Preprocessing:**
**Calibration/NAVIGATION**

**SENSORS:**
- AVHRR
- VIIRS
- MODIS
- AIRS/AMSU
- ATMS
- CrIS
- IASI
- MERSI
- ABI & GLM
- AHI

**EDR/LEV 2**
**Atmospheric/Land/Oceanic PRODUCTS**

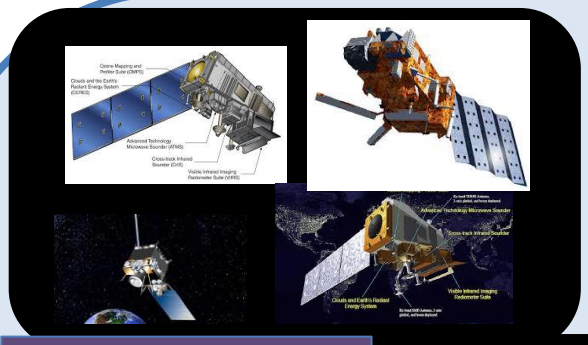
**PRODUCTS:**
- RGB images
- Clouds
- Profiles
- Trace gases
- LST/SST
- Aerosol/Dust
- Fire
- Flood
- Others

**IDR/LEV 3**
**Applications**

Applications:
- Weather forecast
- Fire & Flood
- Air Quality
- Aviation Safety
- Severe Storm

**CSPP S/W Tool Packages:**
- Map Projection --Polar2Grid & Geo2Grid
- Visualization – HYDRA & RealEarth

https://cimss.ssec.wisc.edu/cspp/ & https://cimss.ssec.wisc.edu/csppgeo



# CSPP

**CSPP S/W Product Packages:**

- Clouds - $CLAVR_X$
- Profiles & Trace Gases: NUCAPS
- Profiles: HSRTV
- Profiles & Clouds: MIRS
- SST: ACSPO
- Flood Detection: Flood
- Active Fire: Fire
- ATOVS: IAPP
- Clouds & Profile: GeoAIT/GRB/GVAR
- Imagery clouds, aerosol & LST - AITF
- Clouds, Fog - GEOCAT

**SATELLITES:**

- S-NPP
- NOAA-20
- TERRA/AQUA
- METOP-A/-B
- FY-3C/3D
- GOES-15/16/17
- HIMAWARI

**SDR/LEV 1**
**Preprocessing:**
**Calibration/NAVIGATION**

**EDR/LEV 2**
**Atmospheric/Land/Oceanic PRODUCTS**

**IDR/LEV 3**
**Applications**

**CSPP S/W Tool Packages:**

- Map Projection --Polar2Grid & Geo2Grid
- Visualization – HYDRA & RealEarth

**SENSORS:**

- AVHRR
- VIIRS
- MODIS
- AIRS/AMSU
- ATMS
- CrIS
- IASI
- MERSI
- ABI & GLM
- AHI

**PRODUCTS:**

- RGB images
- Clouds
- Profiles
- Trace gases
- LST/SST
- Aerosol/Dust
- Fire
- Flood
- Others

Applications:

- Weather forecast
- Fire & Flood
- Air Quality
- Aviation Safety
- Severe Storm

https://cimss.ssec.wisc.edu/cspp/ & https://cimss.ssec.wisc.edu/csppgeo

# CSPP

**CSPP S/W Product Packages:**

- Clouds - $CLAVR_X$
- Profiles & Trace Gases: NUCAPS
- Profiles: HSRTV
- Profiles & Clouds: MIRS
- SST: ACSPO
- Flood Detection: Flood
- Active Fire: Fire
- ATOVS: IAPP
- Clouds & Profile: GeoAIT/GRB/GVAR
- Imagery clouds, aerosol & LST - AITF
- Clouds, Fog - GEOCAT

**SATELLITES:**

- S-NPP
- NOAA-20
- TERRA/AQUA
- METOP-A/-B
- FY-3C/3D
- GOES-15/16/17
- HIMAWARI

**SDR/LEV 1**
**Preprocessing:**
**Calibration/NAVIGATION**

**EDR/LEV 2**
**Atmospheric/Land/Oceanic PRODUCTS**

**IDR/LEV 3**
**Applications**

**SENSORS:**

- AVHRR
- VIIRS
- MODIS
- AIRS/AMSU
- ATMS
- CrIS
- IASI
- MERSI
- ABI & GLM
- AHI

**PRODUCTS:**

- RGB images
- Clouds
- Profiles
- Trace gases
- LST/SST
- Aerosol/Dust
- Fire
- Flood
- Others

Applications:

- Weather forecast
- Fire & Flood
- Air Quality
- Aviation Safety
- Severe Storm

**CSPP S/W Tool Packages:**

- Map Projection --Polar2Grid & Geo2Grid
- Visualization – HYDRA & RealEarth

https://cimss.ssec.wisc.edu/cspp/ & https://cimss.ssec.wisc.edu/csppgeo

# NUCAPS Product – Vertical Atmospheric Measurements of thermodynamic parameters and trace gas species

| gas | Precision | d.o.f. | Interfering Parameters | Sensitivity |
|---|---|---|---|---|
| Temperature Profile, T(p), SST, LST | 1.5K/km | 6-10 | Emissivity, $H_2O$, $O_3$, $N_2O$ | surface to ~1 mb |
| Water Profile, $H_2O$(p) | 15% | 4-6 | $CH_4$, $HNO_3$ | surface to ~300 mb |
| Cloud Top Pressure<br>Cloud fraction | 25 mbar,<br>1.5K, 5% | 2<br>18 | $CO_2$, $H_2O$ | surface to tropopause |
| Ozone, $O_3$ | 10% | 1+ | $H_2O$, emissivity | Lower stratosphere |
| Carbon Monoxide, CO | 15% | ≈ 1 | $H_2O$, $N_2O$ | Mid-troposphere |
| Methane, $CH_4$ | 1.5% | ≈ 1 | $H_2O$, $HNO_3$, $N_2O$ | Mid-troposphere |
| Carbon Dioxide, $CO_2$ | 0.5% | ≈ 1 | $H_2O$, $O_3$, T(p) | Mid-troposphere |
| Sulfur Dioxide, $SO_2$ | ≈ 50% | < 1 | $H_2O$, $HNO_3$ | Volcanic flag |
| Nitric Acid, $HNO_3$ | ≈ 50% | < 1 | emissivity $H_2O$, $CH_4$, $N_2O$ | Upper troposphere |
| Nitrous Oxide, $N_2O$ | ≈ 5% | < 1 | $H_2O$, CO | Mid-troposphere |

# Summary of products from NUCAPS Algorithm (in AWIPS-II)

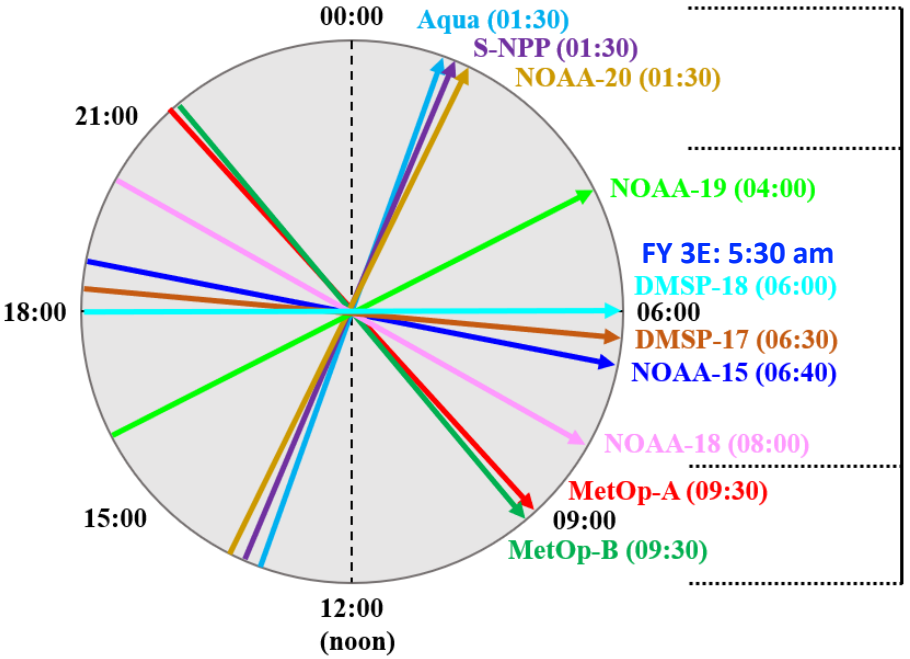
| gas | Range ($cm^{-1}$) | Precision | Interfering Gases | Sensitivity |
|---|---|---|---|---|
| T | 650-800<br>2375-2395 | 1.5K/km | H2O,O3,N2O<br>emissivity | surface to<br>~1 mb |
| $H_2O$ | 1200-1600 | 15% | CH4, HNO3 | surf to 300 mb |
| Cloud P, T, fraction | 700-900 | 25 mbar,<br>1.5K, 5% | CO2, H2O | surface to tropopause |
| $O_3$ | 1025-1050 | 10% | H2O,emissivity | Lower strat. |
| CO | 2080-2200 | 15% | H2O,N2O | Mid-trop |
| $CH_4$ | 1250-1370 | 1.5% | H2O,HNO3,N2O | Mid-trop |
| $CO_2$ | 680-795<br>2375-2395 | 0.5% | H2O,O3<br>T(p) | Mid-trop |
| Volcanic $SO_2$ | 1340-1380 | 50% ?? | H2O,HNO3 | flag |
| $HNO_3$ | 860-920<br>1320-1330 | 50% ?? | emissivity<br>H2O,CH4,N2O | Upper trop |
| $N_2O$ | 1250-1315<br>2180-2250 | 5% ?? | H2O<br>H2O,CO | Mid-trop |

# CSPP CrIS/ATMS, IASI/AMSU, and HIRAS/MWTS/MWHS

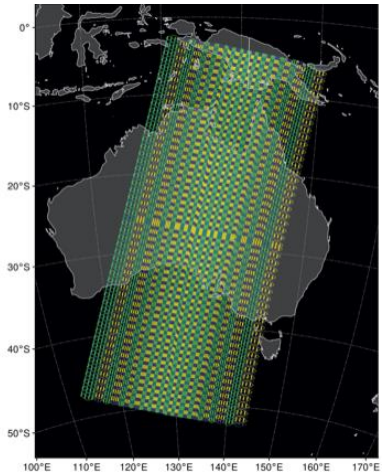
Hyperspectral/Microwave Combined Sounding Profile Coverage
(5:50 am. 9:30 am & 1:30 pm)

## NUCAPS for HIRAS/MWTS-2/MWHS-2 Hyperspectral IR & Microwave sounding retrieval

Software for retrieving atmospheric profiles of temperature, moisture, trace gases and cloud-cleared radiances from direct broadcast (DB) HIRAS/MWTS/MWHS Sensor Data Records (SDRs) for FY3D/3E and beyond







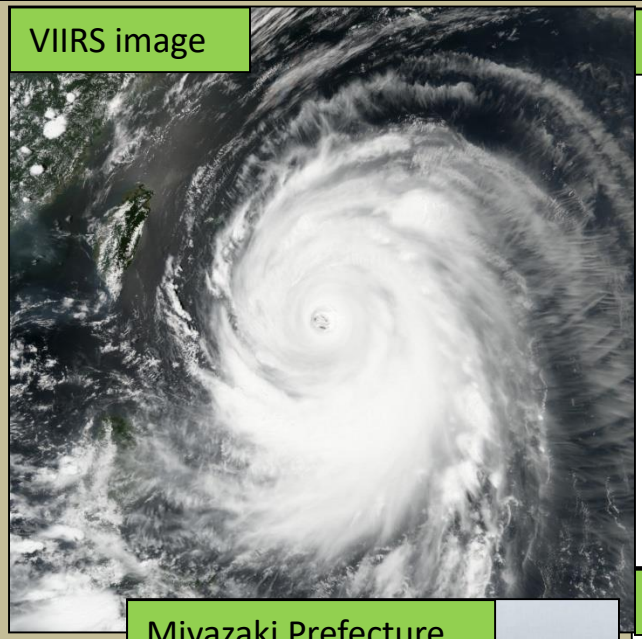
# Development of NUCAPS for CSPP Real-Time Processing of FY3E Hyperspectral Sounding Suites

Agnes Lim, Zhenglong L., Jim D., Chris Barnet, Allen Huang

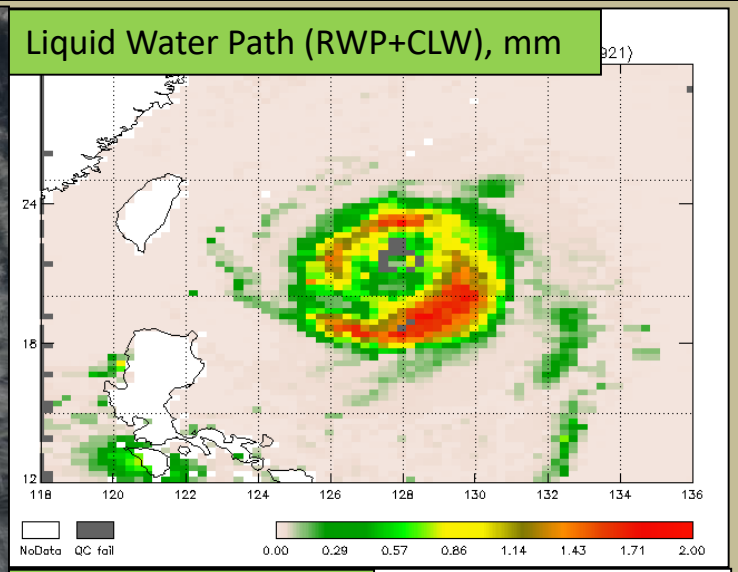
With S-NPP/NOAA-20 and the future JPSS satellites flying in early afternoon orbits, METOP satellite series flying in mid-morning orbits, the FY satellites fill in the orbital gaps with FY-3D 30 minutes after NOAA-20 and FY-3E in the early morning orbit. The FY-3 satellites carry the Hyperspectral Infrared Atmospheric Sounder (HIRAS) and Micro-Wave Temperature/Humidity Sounder-2 (MWTS-2 and MWHS-2) which are similar to CrIS/ATMS and IASI/AMSU class of advanced satellite sounding suites. NOAA NWS field offices are provided with two-orbit coverage (9:30 and 13:25) of NUCAPS sounding profiles that are used routinely to assist forecasters in monitoring and forecasting short life cycle convective storms. **The FY-3D/3E soundings will mitigate the significant gaps that limit the forecasters' ability to monitor and near-cast the short-lived convective storms.**

# MiRS V11 Rainfall: Typhoon Neoguri on 7 July 2014

VIIRS image



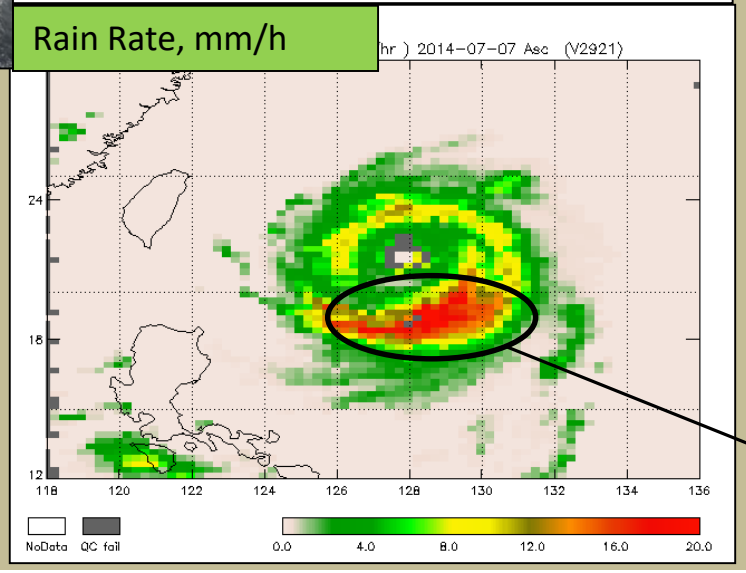
Liquid Water Path (RWP+CLW), mm




- SNPP/ATMS data
- Cyclone impacted Okinawa on 8 July

Miyazaki Prefecture

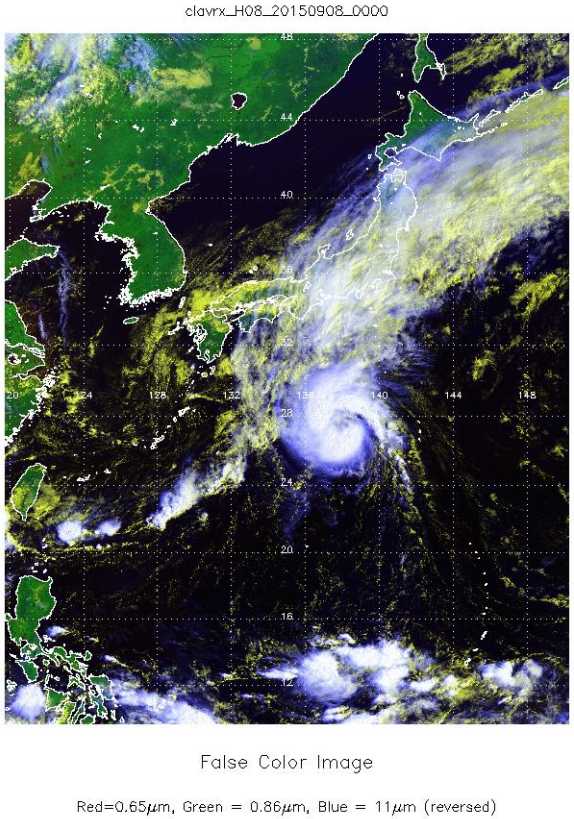
Rain Rate, mm/h



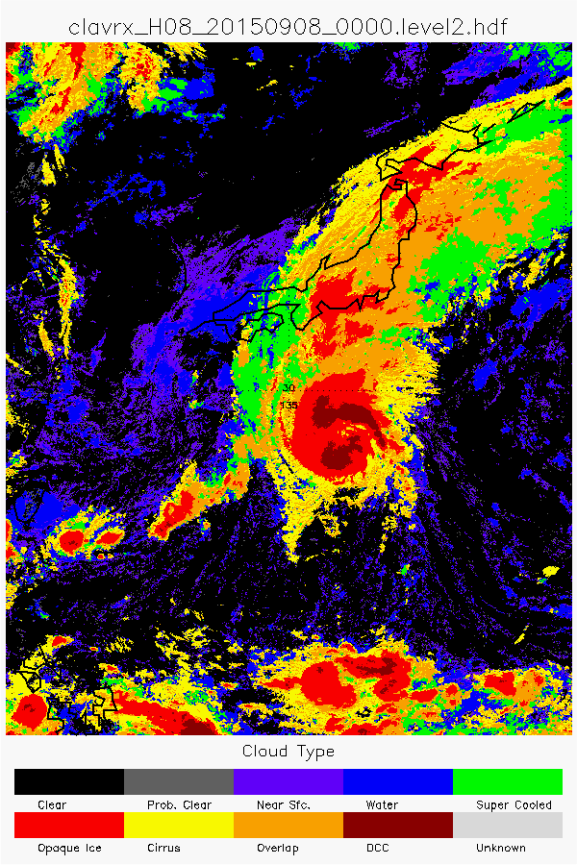

**RR > 20 mm/h consistent with reports post-landfall (e.g. 340 mm in 24 h)**

# CSPP Geo CLAVR-x Cloud Products on AHI (1)

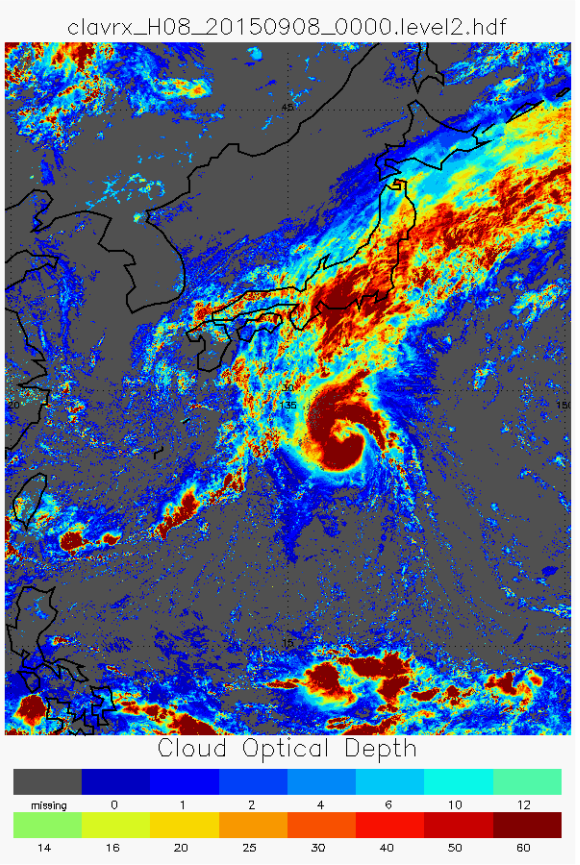
False Color Image (0.65, 0.86, 11μm)




Cloud Type



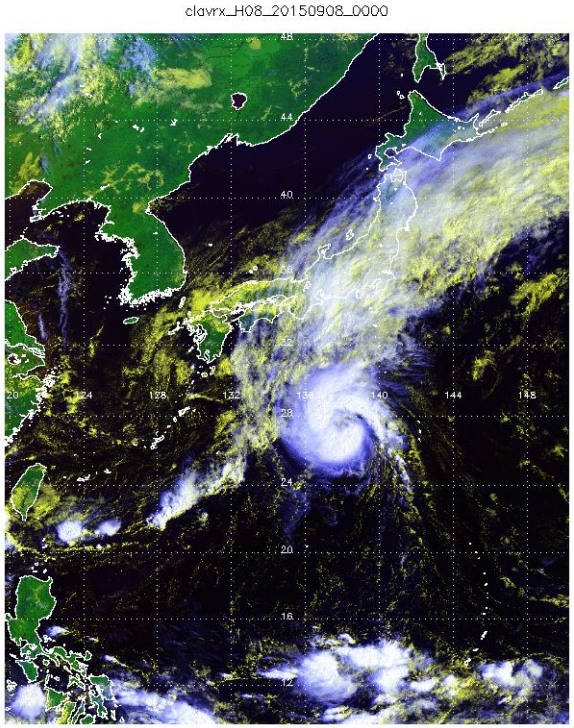

Cloud Optical Depth



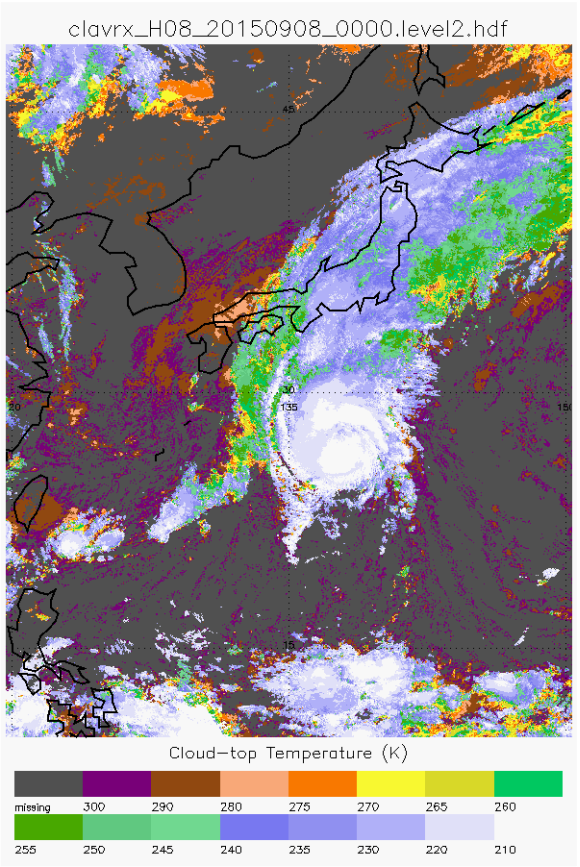

Himawari 8 - AHI, TS Etau, September 8, 2015

# CSPP Geo CLAVR-x Cloud Products on AHI (2)

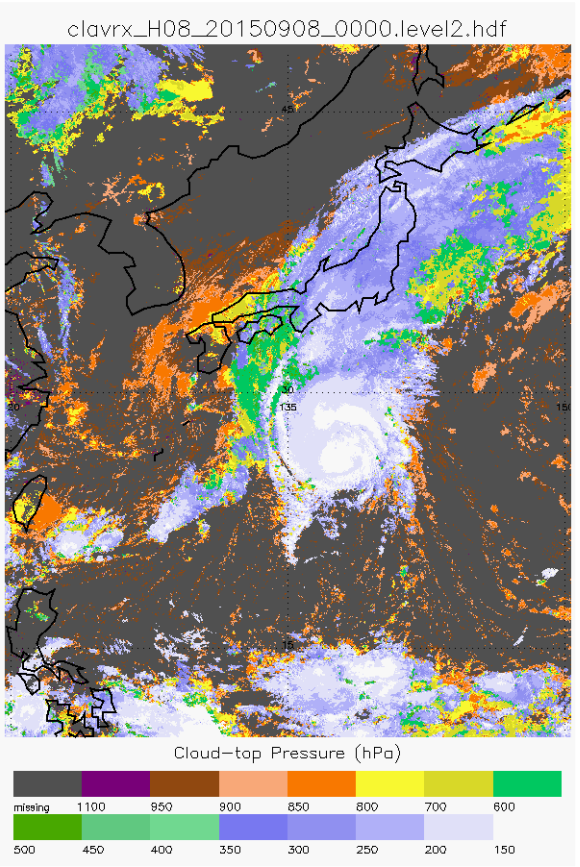
False Color Image (0.65, 0.86, 11μm)




Cloud Top Temperature




Cloud Top Pressure




Himawari 8 - AHI, TS Etau, September 8, 2015

# Facilitating Exploitation of International LEO/GEO Meteorological Satellite Observing Systems Through Community Satellite Processing Package (CSPP)

## *EDR - Summary (1/7)*

✓ **NUCAPS (NOAA Unique Combined Atmospheric Processing System):**

•Cloud-cleared Radiances (NUCAPS-CCR-AR_v3r0_*.nc files),

•Outgoing Longwave Radiation (NUCAPS-OLR_v3r0_*.nc files),

•and Environmental Data Record (EDR) vertical profiles of temperature, moisture and trace gasses (NUCAPS-EDR_v3r0_*.nc files) including:

- Atmospheric temperature [K] at 100 pressure levels
- Atmospheric moisture [g/g] at 100 pressure levels
- Atmospheric ozone [ppb] at 100 pressure levels
- Atmospheric liquid water [g/g] at 100 pressure levels
- Carbon dioxide dry mixing ratio [ppm] at 100 pressure levels
- Trace gas mixing ratios CO, CH4, HNO3, N2O, SO2* [ppb] at 100 pressure levels
- Surface skin temperature [K]
- Microwave surface emissivity
- Column averaged CO2 per ATMS or AMSU Field-Of-View (FOV) [ppm]
- Cloud top pressure for up to two cloud layers [hPa]
- Cloud top fractional coverage for up to two cloud layers
- 10 Stability parameters including CAPE, Lifted Index (LI) and Convective Inhibition (CIN)
- Quality flags

# Facilitating Exploitation of International LEO/GEO Meteorological Satellite Observing Systems Through Community Satellite Processing Package (CSPP)

## *EDR - Summary (2/7)*

✓ **HSRTV: CrIS, AIRS and IASI Hyperspectral Retrieval:**

Atmospheric temperature [K] at 101 pressure levels

- Atmospheric moisture [g/kg] at 101 pressure levels
- Atmospheric ozone [ppmv] at 101 pressure levels
- Atmospheric relative humidity [%] at 101 pressure levels
- Atmospheric dew point temperature [K] at 101 pressure levels
- Surface skin temperature [K]
- Surface emissivity at instrument spectral resolution [cm-1] (under clear conditions only)
- Total precipitable water (vertically integrated from 100 hPa to surface) [cm]
- Precipitable water 1 (vertically integrated from 900 hPa to surface) [cm]
- Precipitable water 2 (vertically integrated from 700 to 900 hPa) [cm]
- Precipitable water 3 (vertically integrated from 300 to 700 hPa) [cm]
- Total ozone amount (vertically integrated) [dobson units]
- Lifted index [Degrees Celsius]
- Convective available potential energy [J/kg]
- CO2 amount [ppmv]
- Cloud top pressure 1 [hPa]
- Cloud top temperature 1 [K]
- Cloud optical thickness
- Effective cloud emissivity
- Cloud mask (values: 0 clear, 1 cloud)

# Facilitating Exploitation of International LEO/GEO Meteorological Satellite Observing Systems Through Community Satellite Processing Package (CSPP)

## *EDR - Summary (3/7)*

✓ **MiRS (Microwave Integrated Retrieval System (MiRS):**

- Temperature profile over open water ocean
- Humidity profile over open water ocean
- Humidity profile over non-coastal Land
- Total Precipitable Water (TPW) over open water ocean
- Total Precipitable Water over non-coastal land
- Land surface temperature
- Surface Emissivity over land and snow
- Snow Water Equivalent (SWE)
- Sea Ice Concentration (SIC)
- Snow Cover Extent (SCE), based on the SWE
- Vertically-Integrated Non-precipitating Cloud Liquid Water (CLW) over open water ocean
- Vertically-Integrated Ice Water Path (IWP)
- Vertically-Integrated Rain Water Path (RWP)
- Rainfall Rate (RR) over open water ocean and non-coastal, non-snow-covered land surface types
- Effective grain size of snow (over snow-covered land surface)*****
- Multi-Year (MY) Type Sea Ice Concentration*****
- First-Year (FY) Type Sea Ice Concentration*****
- Snow Fall Rate (SFR)**
- Probability of Falling Snow (Prob_SF)**

# Facilitating Exploitation of International LEO/GEO Meteorological Satellite Observing Systems Through Community Satellite Processing Package (CSPP)

## *EDR - Summary (4/7)*

✓ **CLAVR-x (Clouds from AVHRR Extended):**

- cloud mask,
- cloud type (13 categories),
- cloud height,
- cloud top pressure,
- cloud top temperature,
- cloud emissivity,
- cloud optical depth,
- cloud effective radius,
- cloud phase,
- rain rate (experimental),
- VIIRS lunar reflectances,
- VIIRS nighttime cloud optical depth,
- VIIRS nighttime cloud effective radius,
- product quality flags.

Cloud products are also created for MODIS & AVHRR

# Facilitating Exploitation of International LEO/GEO Meteorological Satellite Observing Systems Through Community Satellite Processing Package (CSPP)

## *EDR - Summary (5/7)*

✓ **VIIRS Active Fire:**

•Latitude of fire pixel (degrees).
•Longitude of fire pixel (degrees).
•M-Band 13 brightness temperature of fire pixel (K) or I-Band 4 brightness temperature of fire pixel (K).
•Along-scan fire pixel resolution (km).
•Along-track fire pixel resolution (km).
•Fire detection confidence.
•Fire radiative power (MW).
•Persistent Anomaly category (1-5) (I-Band only).

# Facilitating Exploitation of International LEO/GEO Meteorological Satellite Observing Systems Through Community Satellite Processing Package (CSPP)

## *EDR - Summary (6/7)*

✓ **GCOM-W1 AMSR2 Algorithm Software Package (GAASP):**

- **Preprocessor:**
  - Applies bias corrections and assigns an RFI flag to input L1B files.
- **Ocean**
  - Sea Surface Temperatures, Sea Surface Winds, Cloud Liquid Water, Total Precipitable Water.
- **Precipitation:**
  - Convective Precipitation, Surface Rain Rate.
- **Soil Moisture:**
  - Land Cover Type, Soil Moisture.
- **Snow:**
  - Snow Cover, Snow Depth.
- **Sea Ice:**
  - Bootstrap Ice Concentration, NASA Team 2 (NT2) Ice Concentration, NASA Team 2 Multiyear Ice, NT2 minus Bootstrap, Range of Ice Concentration.
- **Postprocessor:**
  - Converts the GAASP-*.h5 output files described above to CF-compliant NetCDF4.

# Facilitating Exploitation of International LEO/GEO Meteorological Satellite Observing Systems Through Community Satellite Processing Package (CSPP)

## *EDR - Summary (7/7)*

- ✓ **VIIRS Surface Reflectance and Vegetation Index**
- ✓ **VIIRS Aerosol, Snow/Ice, Cloud, Volcanic Ash (ASCI), and Land Environmental Data Record (EDR)**
- ✓ **Advanced Clear-Sky Processor for Oceans (ACSPO):**
  - SST of VIIRS, MODIS & AVHRR
- ✓ **VIIRS Flood**

**CSPP, a community-based infrastructure, readily used by LEO/GEO satellite users for various weather & environmental Applications**

http://cimss.ssec.wisc.edu/cspp/

# Questions are Welcome!!!