JPSS Enterprise Review: Cloud Products

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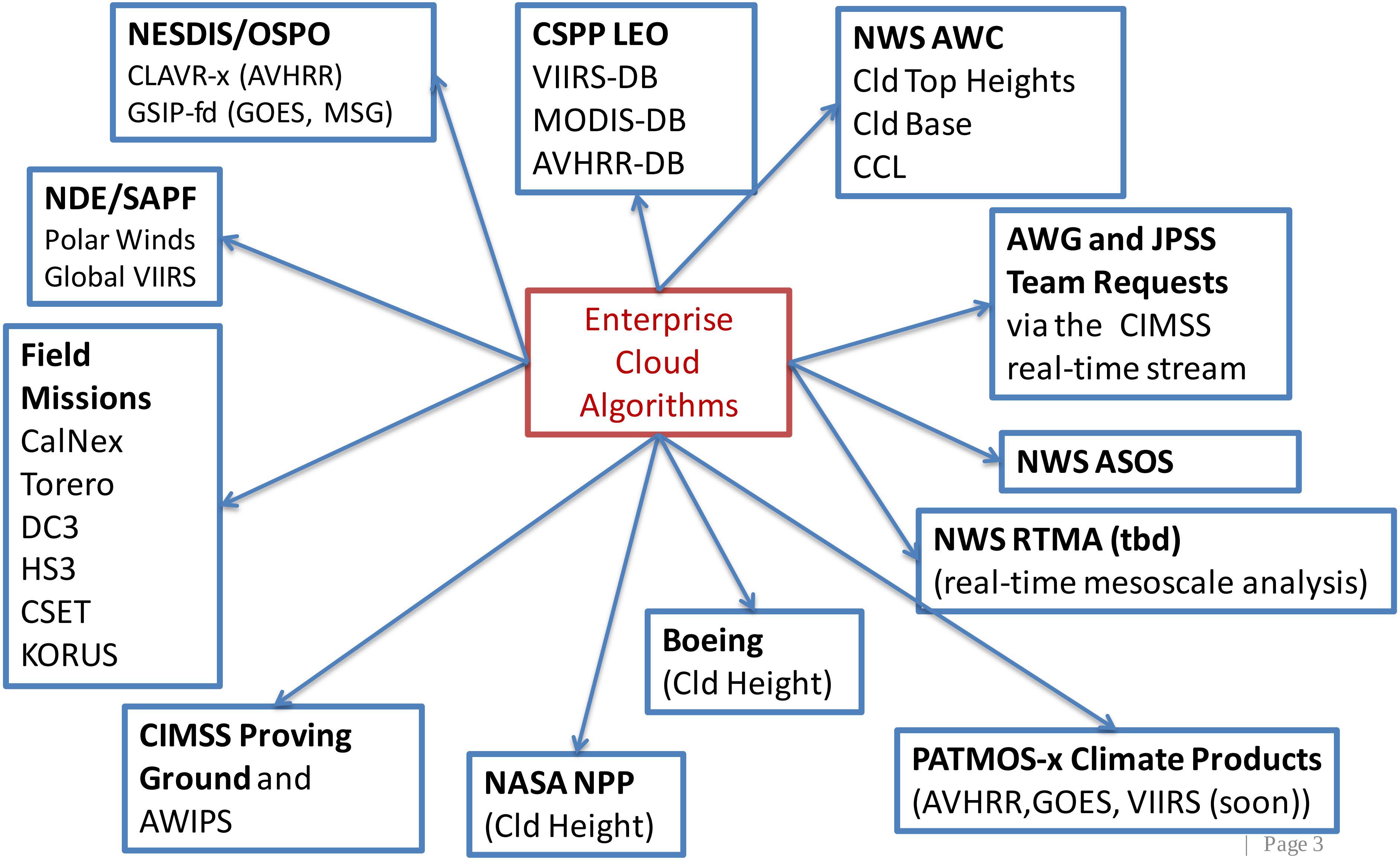
Cloud Team Sub-Groups

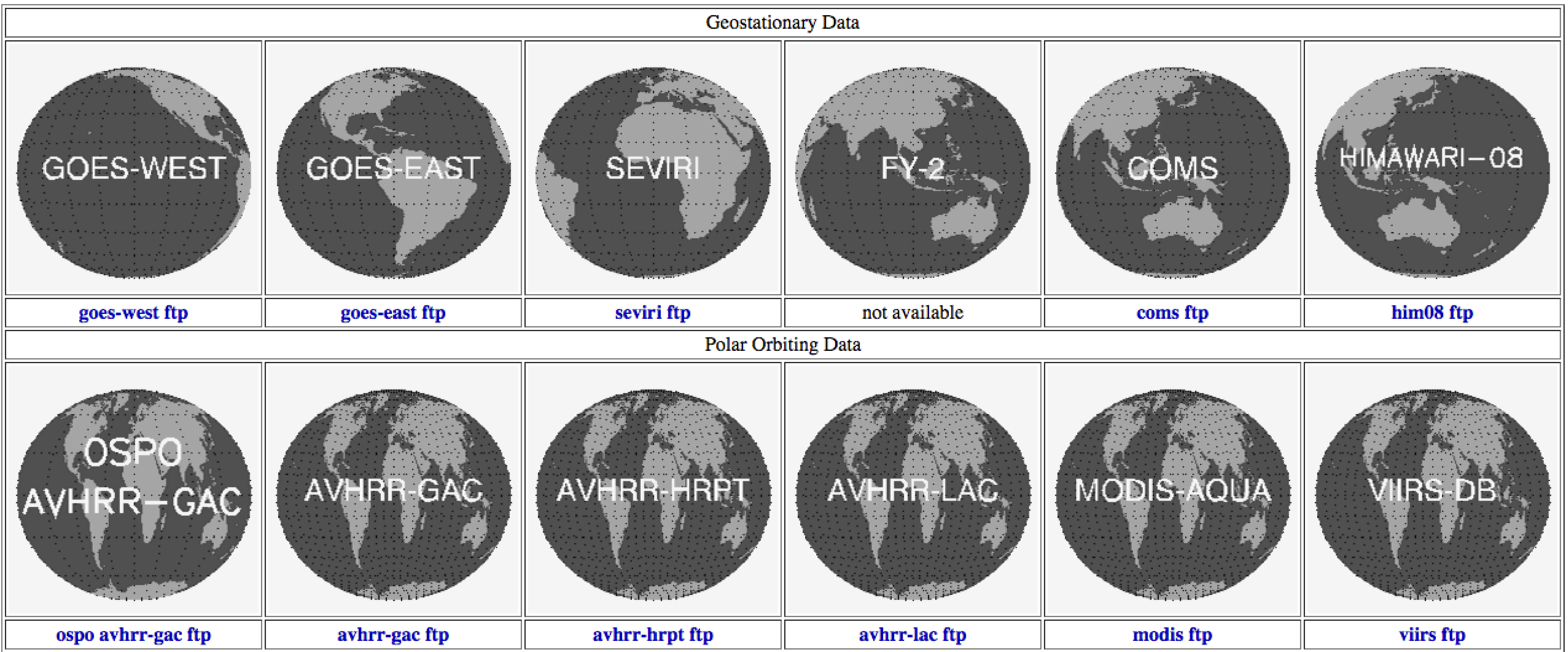
- Mask Team
  - Tom Kopp (Aero), Andrew Heidinger (NOAA), Denis Botambekov (CIMSS) and Andi Walther (CIMSS).
- Phase Team
  - Mike Pavolonis (NOAA), Corey Calvert and Jason Brunner (CIMSS)
- Height Team
  - Andrew Heidinger (NOAA), Yue Li and Steve Wanzong (CIMSS)
- Base Team
  - Dan Lindsey (NOAA) and Steve Miller, Y.J. Noh and Curtis Seaman (CIRA)
- D/N COMP Team
  - Andi Walther and Pat Heck(CIMSS)
- AIT Liaisons
  - William Straka (CIMSS) and Ruiyue Chen (AIT)

Enterprise Cloud Product Users



Applicability of Enterprise Algorithms

- This image from the CLAVR-x real-time site shows the current sensors we apply the Enterprise Cloud Algorithms to.
- We are considering Meteosat-7
- We also support MTSAT-2, MTSAT-1R and GOES-IL.
- We should be able to support GOES-R ABI.



Summary of Current Operational Products

- Cloud Mask, Phase, Height and D/N COMP already implemented into AIT SAPF.
- ARR passed for the above algorithms.
- Cloud Base Height implemented this month.
- Cloud Cover Layers will be implemented this summer.
- AIT runs the Enterprise Cloud Algorithms on GOES 13/15, AVHRR, VIIRS, MSG/SEVIRI and AHI.
- CLAVR-x (AVHRR) and GSIP (GOES, SEVIRI) run them and will be phased out over the next year or so and replaced by the SAPF in OSPO

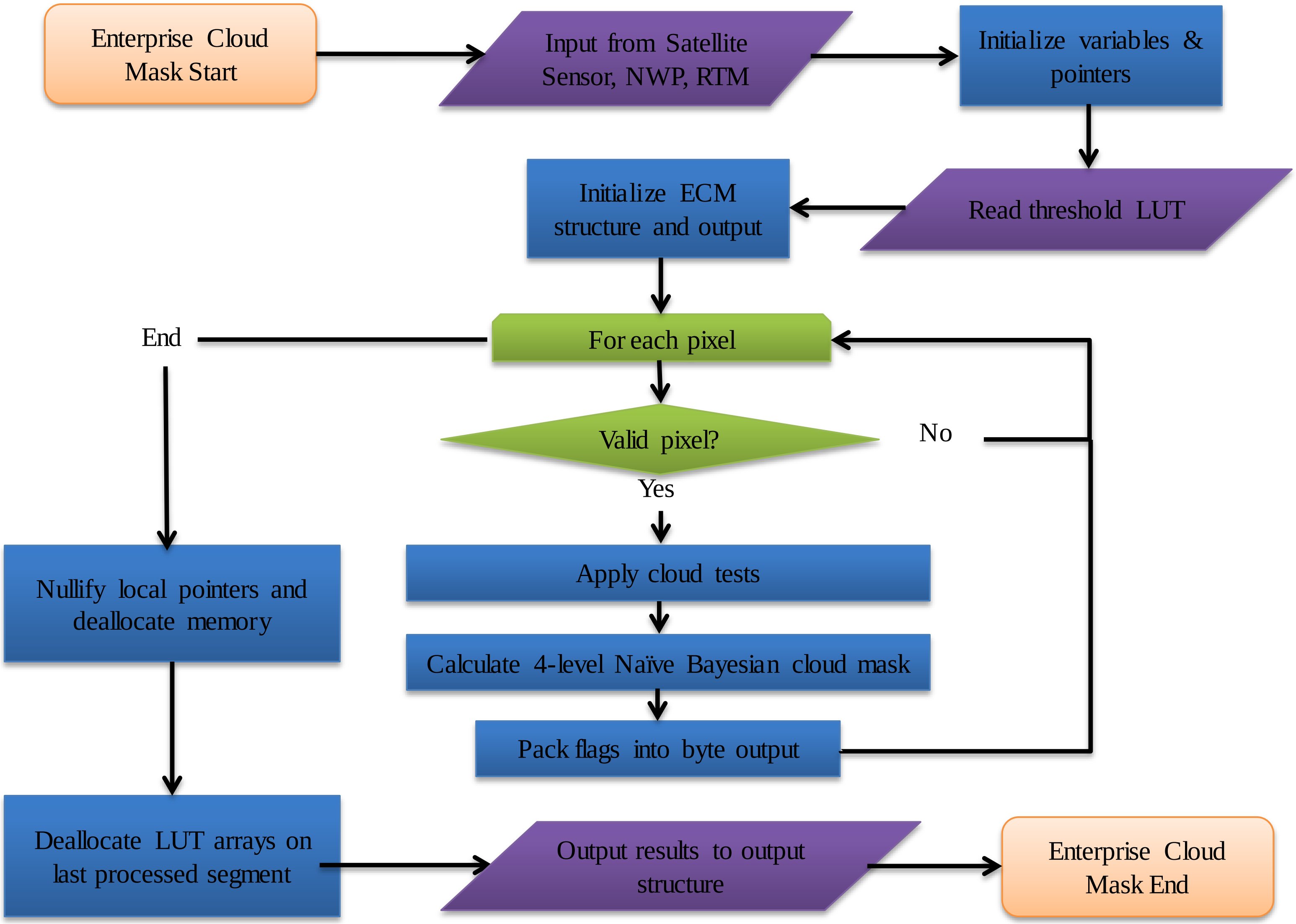
Enterprise Cloud Mask

Enterprise Cloud Mask (ECM)

- ECM is the NOAA Enterprise Cloud Mask
  - ECM makes 4-level cloud mask of each pixel.
  - It allows the downstream products to mask out cloudy or clear pixels.

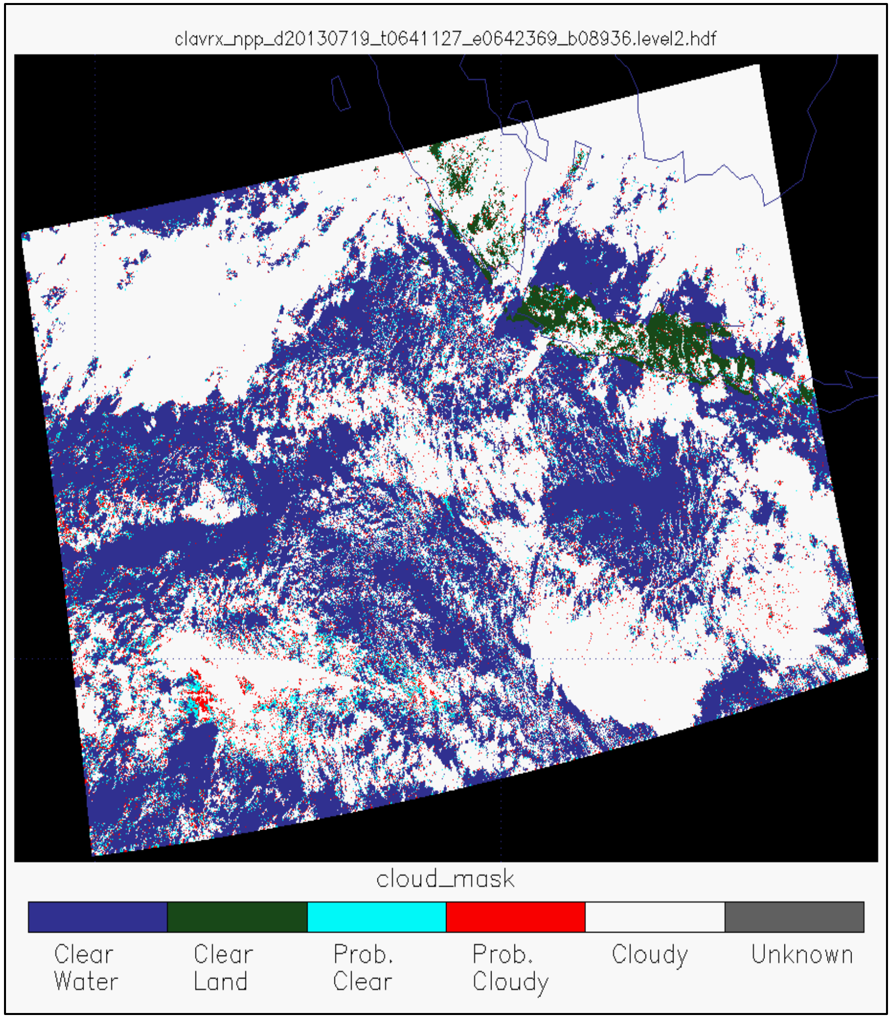
- Users
  - Used as an input to many other baseline products.
  - Potential use in RTMA (NWS)
  - Fundamental driver of cloud layer products

ECM High Level Process Flow



Current Operational Product

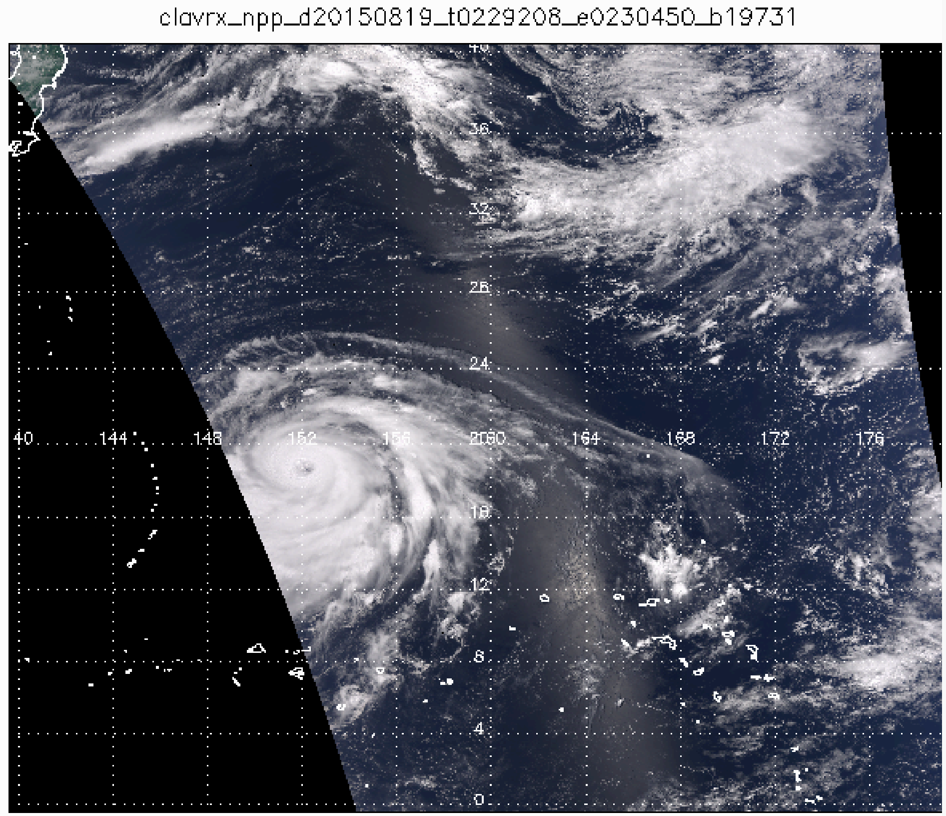
- ECM algorithm
  - Uses the same tests as the GOES-R Baseline Cloud Mask. New tests have been added. Code can turn off/on tests for each sensor.
  - Uses a Naïve Bayesian method to combine tests instead of the traditional sequential mask logic used in GOES-R baseline.
  - ECM officially provides a binary mask (yes/no), which comes from the 4-level mask.
  - Includes adjacency mask, dust, smoke, glint, shadow and fire flags (similar to VCM)



Example: ECM, VIIRS, July 19, 2013 from 06:38:21 to 06:42:36 UTC

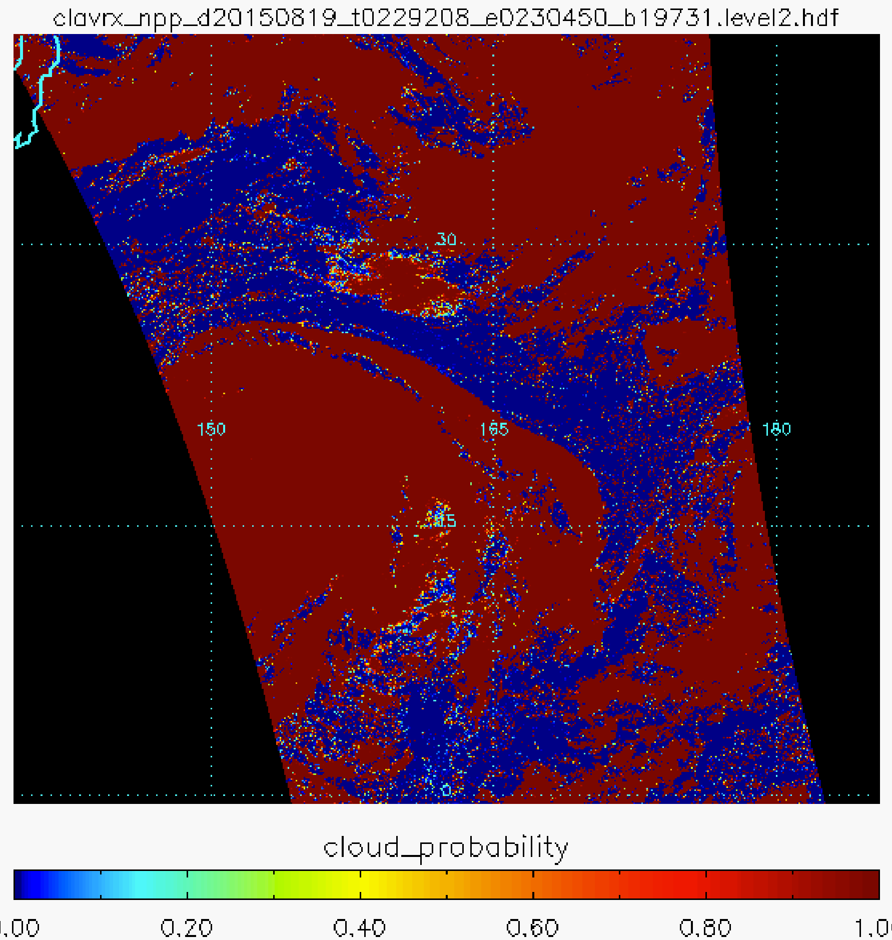
ECM OUTPUT: Cloud Probability

- Primary output of ECM is a cloud probability – varies from 0 to 1.
- For the daytime ocean example shown, most values are near 0 or 1.
- Over some surfaces (arctic night), ECM generates few values near 0 or 1.



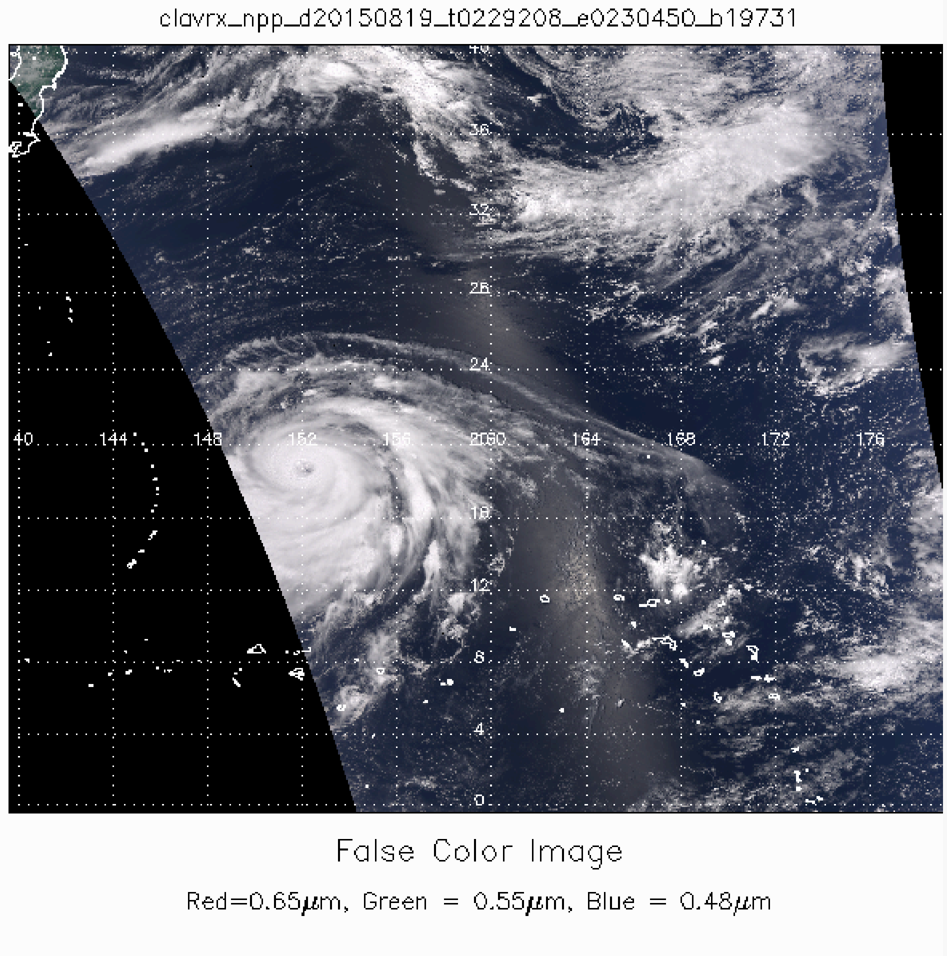
False Color Image

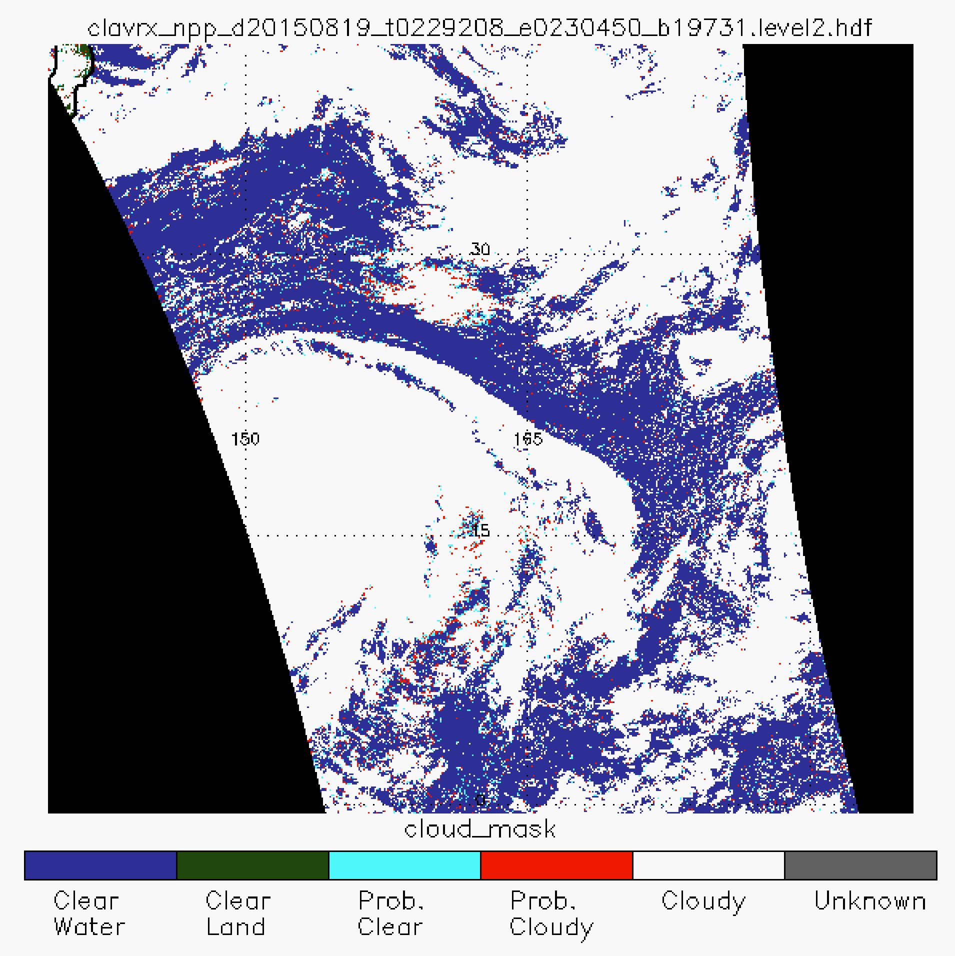
Red=0.65μm, Green = 0.55μm, Blue = 0.48μm



ECM OUTPUT: 4-Level Mask

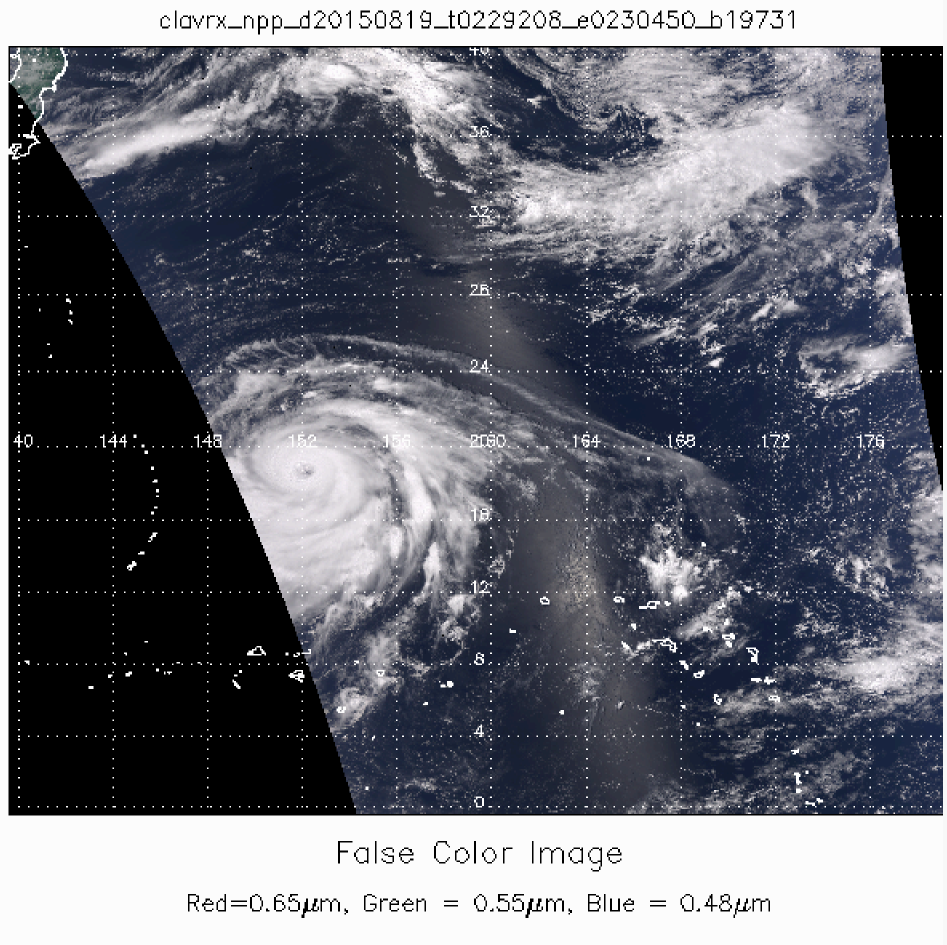
- Definitions same as VCM: 0-Conf Clear, 1-Prob Clear, 2-Prob Cloudy, 3 – Conf Cloudy
- Based on the Probability Values
- Confident Clear is rare over some surfaces – arctic night for example.

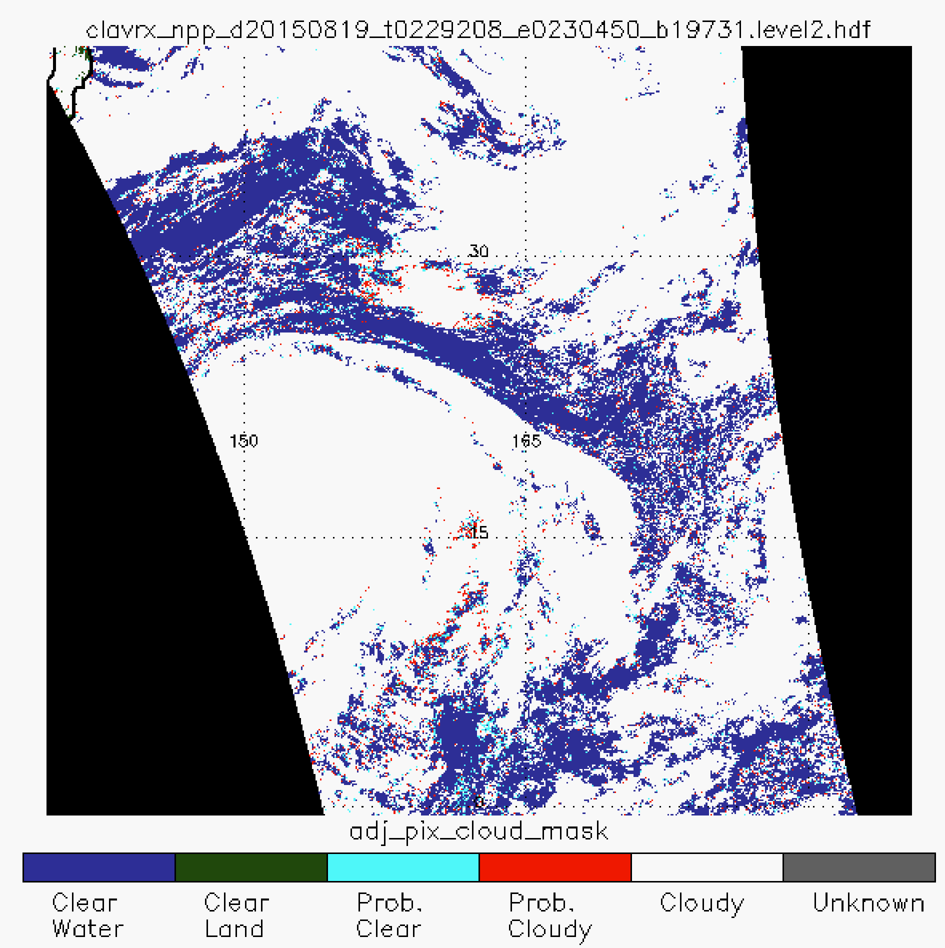




ECM OUTPUT: Adjacency Cloud Mask

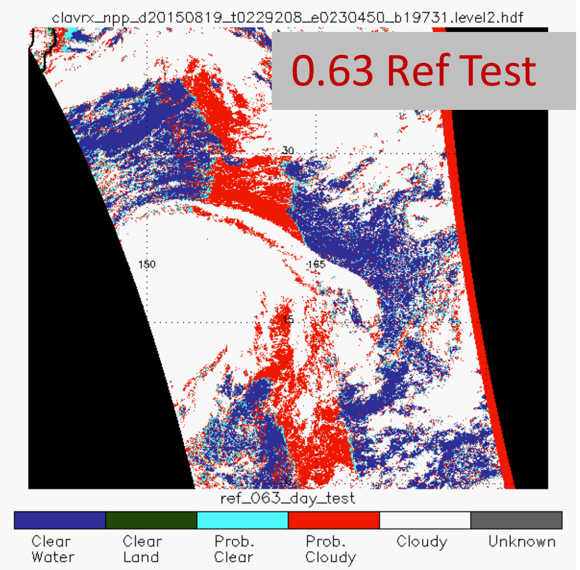
- Definition of ECM Adjacency Mask is the same as the VCM
- Provides a more clear-conservative mask with the assumption that pixels next to clouds are likely cloud contaminated.

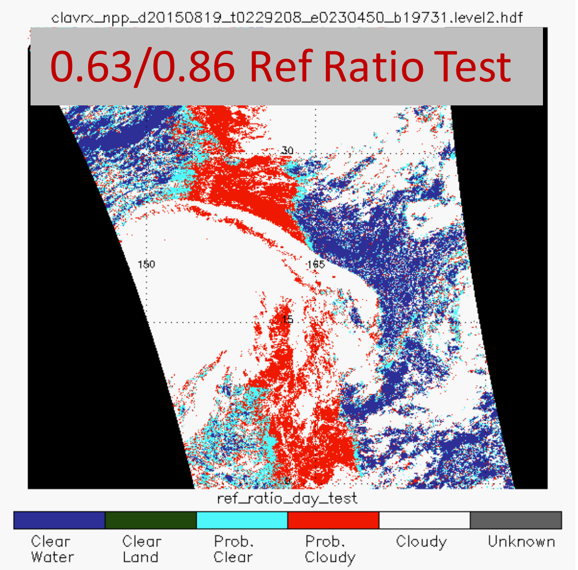




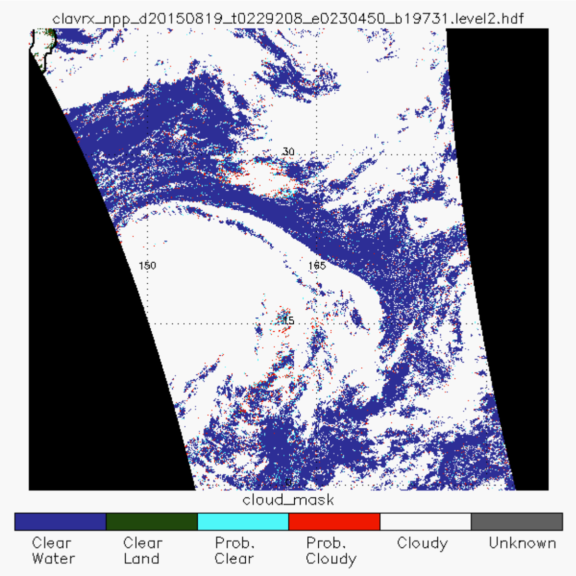
ECM OUTPUT: Individual Test Masks

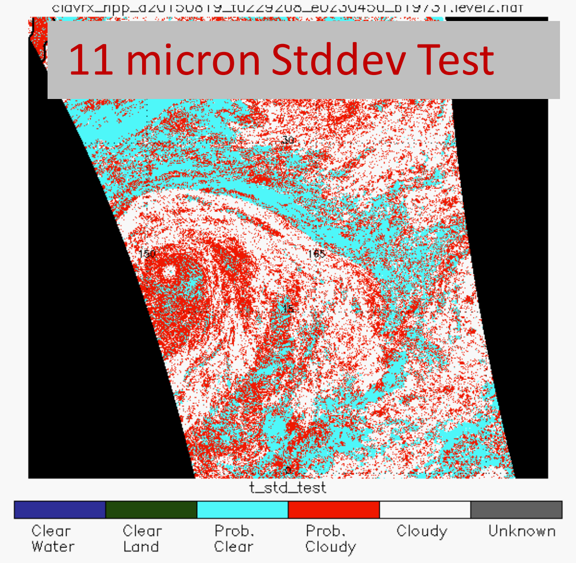
- ECM provides a 4-level mask from each test.
- Individual masks are derived from probabilities from each test alone.
- You can use individual tests to focus on certain features (i.e. cirrus or cloud edges)
- Note, final mask (below) is free of many artifacts seen in the individual test masks.

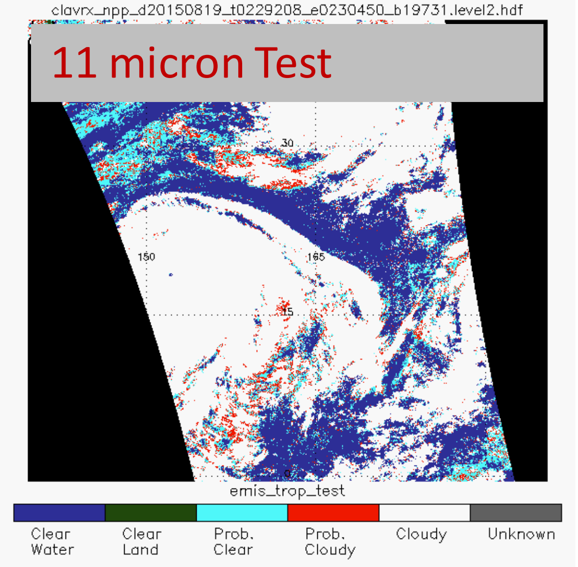




4-Level Mask

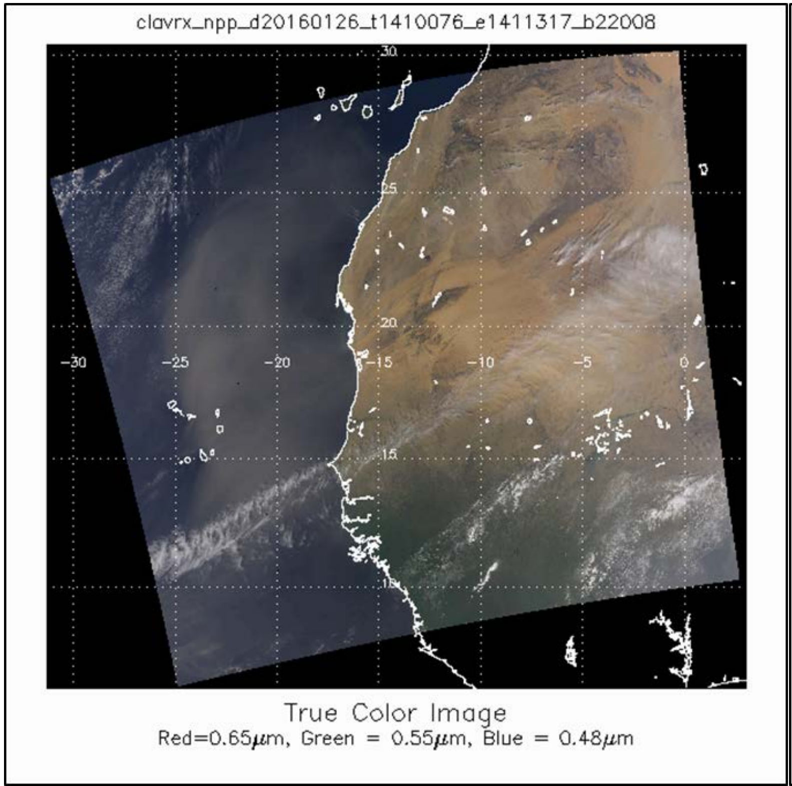


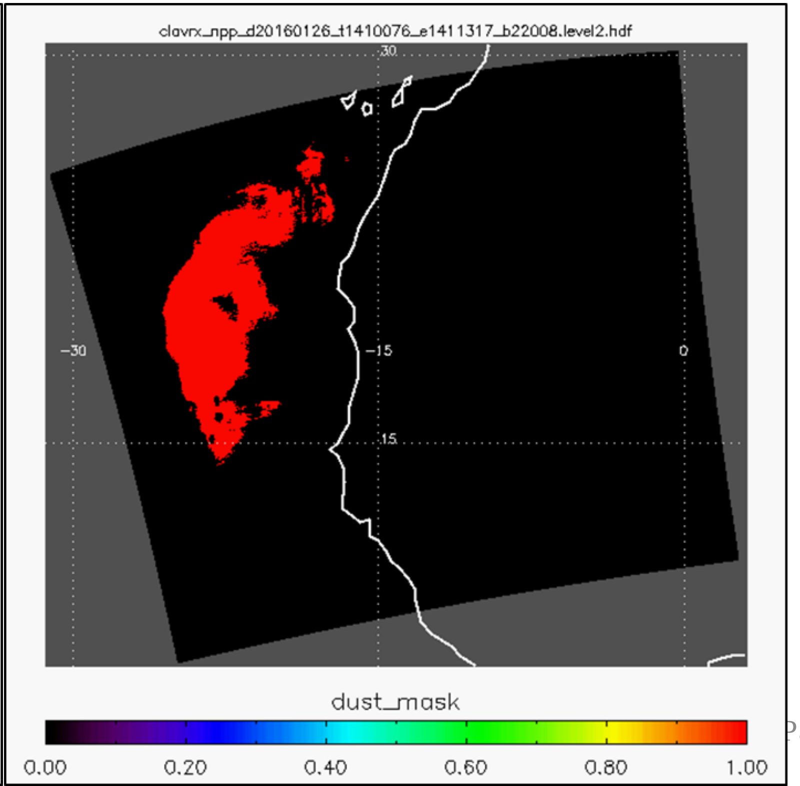




Dust, Smoke and Fire

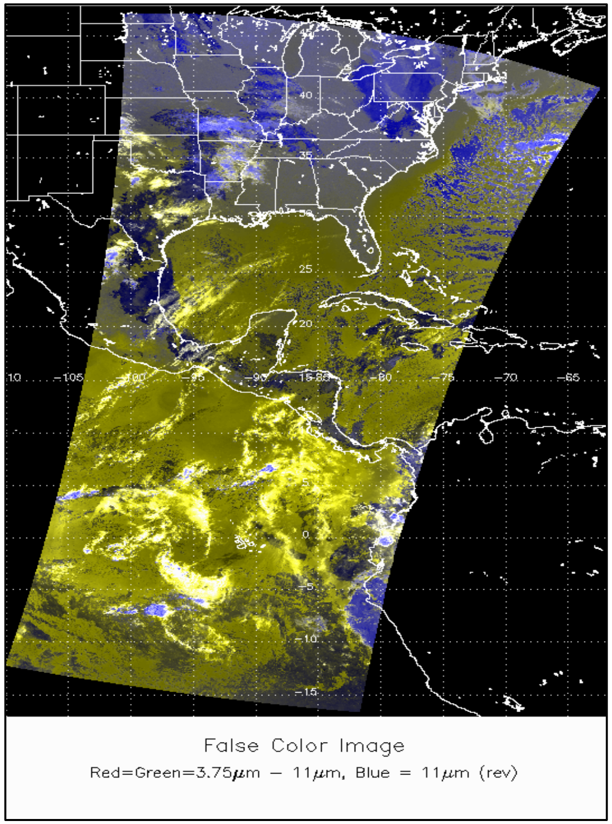
- Cloud mask includes bits that identify glint, shadow, snow, fire, dust and smoke.
- This was a requested capability in 2014. Besides glint and snow, these **do not impact cloud mask – extra information**.
- Goal of these bits is to make a better cloud mask and should not be used to communicate the official snow, fire and aerosol products to downstream applications.
- Glint, dust and smoke are taken from CLAVR-x heritage and **help identify false cloud**.
- Fire bit is our attempt to make signals that cause DNB test to trigger.



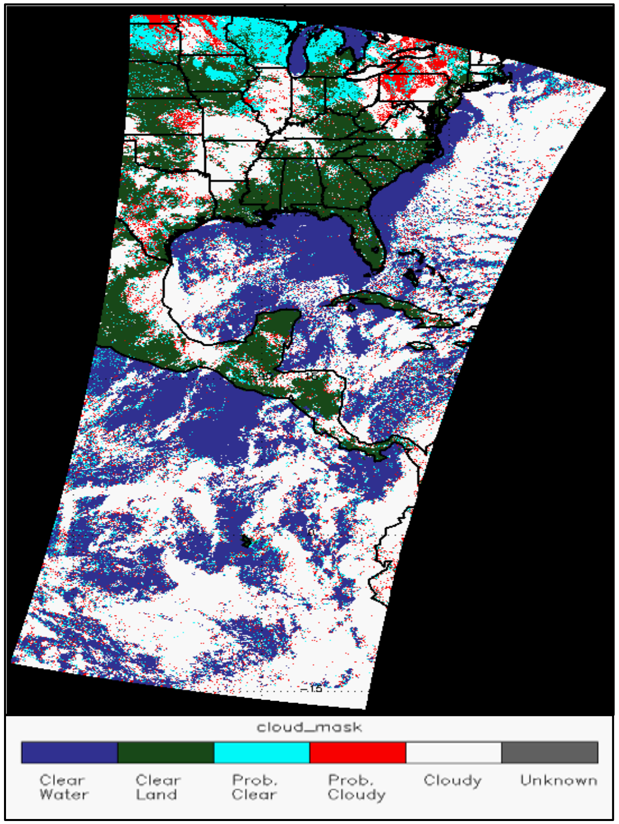


ECM Use of VIIRS DNB Lunar Reflectance

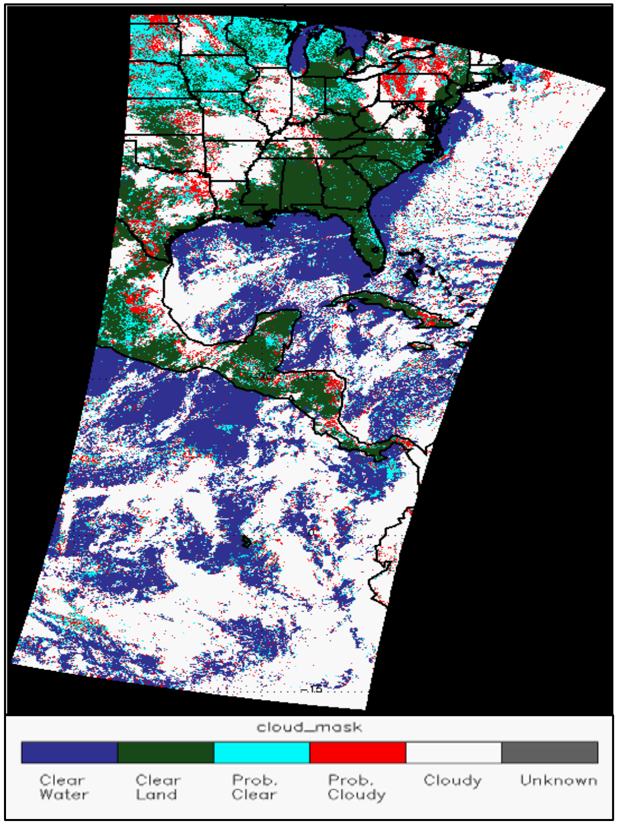
- ECM is designed to use the VIIRS DNB Lunar Reflectance if present.
- SAPF currently does exercise this option.
- Presence of DNB increases the amount of confident detections.



False Color RGB



Cloud Mask with DNB



Cloud Mask no DNB

Nighttime VIIRS, 2013-03-29 07:36 UTC

CIRA group is writing a manuscript on this

Hypothetical ECM DR Resolution

If you see an issue with the ECM tell us. These are the steps we would recommend to try and resolve the issue.

1. Try the adjacency cloud mask.
2. Optimize a new clear-sky mask from the Cloud Probability.
3. Try using the individual tests best suited for the phenomena of interest.
4. Work with us to make longer term changes to the mask.

Lessons Learned

- Making one mask that meets specification of various geo and polar satellites is hard. For example, terminator behavior is very different in geo and leo.
- Success of the ECM is ultimately defined by its users.
- We acknowledge there are ongoing concerns a single mask can satisfy all dependent products.
- Goal of the ECM is to do no harm and provide as much cloud detection information as possible.
- More lessons are expected to be earned once we get feedback.

Path Forward

- Anticipated developments
  - We continue to optimize the existing tests and thresholds.
  - Low cloud detection skill is lower than we think it should be and we are exploring modifications to the logic.
  - Polar uncertainties are also lower than desired but in line with MODIS.
  - Continue to evolve the use of the DNB in the ECM.
  - We expect to work these in gradually within the scheduled updates to ECM (3-4 times per year).
  - Tom Kopp will help in this function as he did with the VCM and we encourage teams to call in or schedule time at future meetings.

- Upcoming Deliveries/Reviews
  - We expect another update in the Summer 2016.

- Risks
  - No risk is anticipated but we need more buy-in from the teams to fully assess risk for all applications.

Summary

- Outstanding issues

  – The ECM is stable and fully implemented in the SAPF.

  – SAPF runs it now on many sensors and makes data available to other teams.

  – We look forward to working the teams and providing what they need for cloud detection.

Enterprise Cloud Phase / Type

Cloud Top Phase and Cloud Type

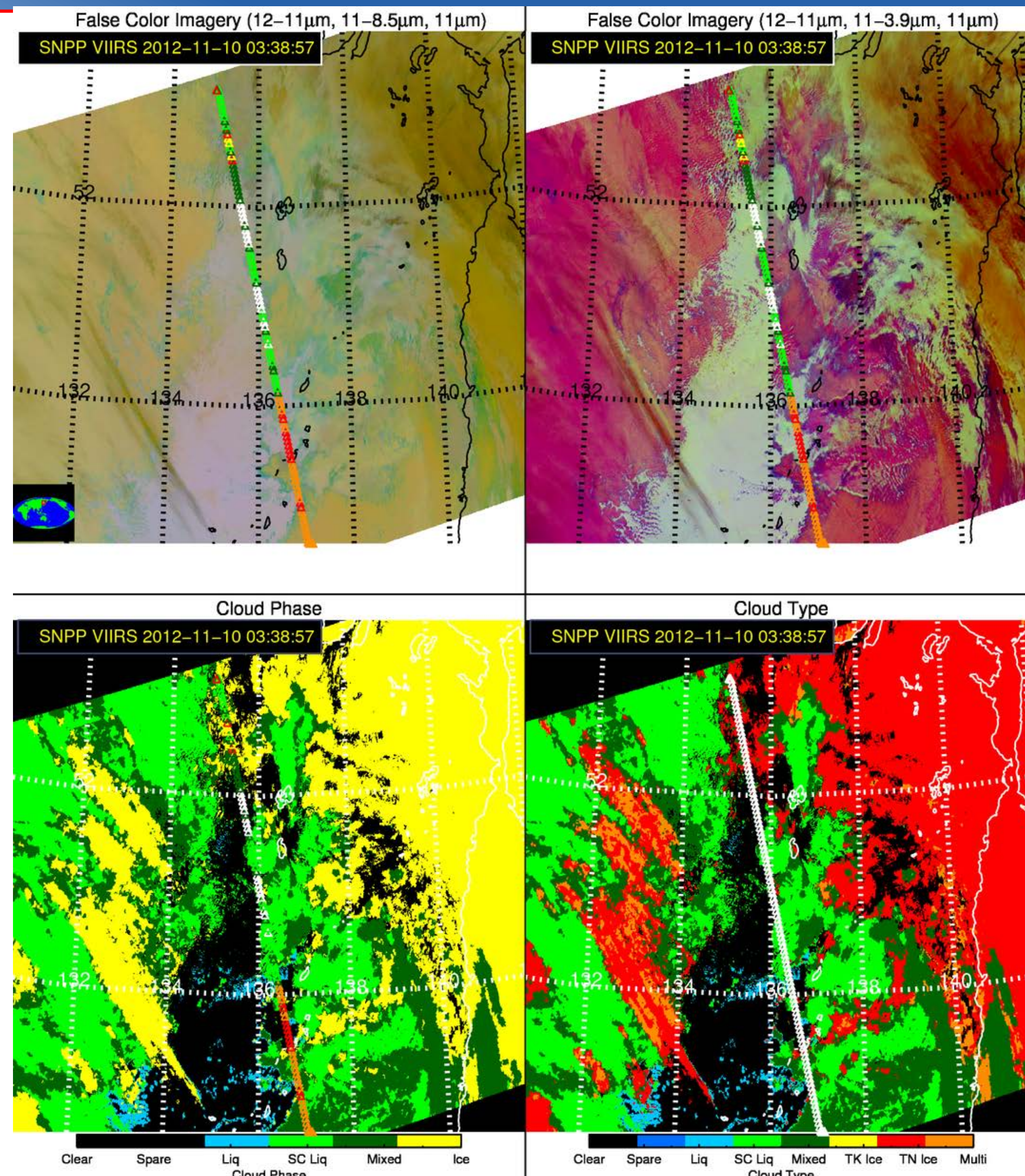
Primary Users: Downstream cloud products (cloud height and optical properties), the fog/low stratus application developed by the GOES-R AWG, NWS forecasters for aviation applications

Plans for JPSS1:

Maintenance - Optimize cloud phase thresholds for JPSS-1 when VIIRS data from JPSS-1 become available

Monitoring - Periodically compare VIIRS cloud phase to CALIOP derived cloud phase to ensure stable and consistent performance

Development - Explore use of additional VIIRS vis/nir channels and CrIS absorption channels for improving the VIIRS multilayered cloud detection



Enterprise Cloud Top Properties from the AWG Cloud Height Algorithm (ACHA)

Cloud Top Properties

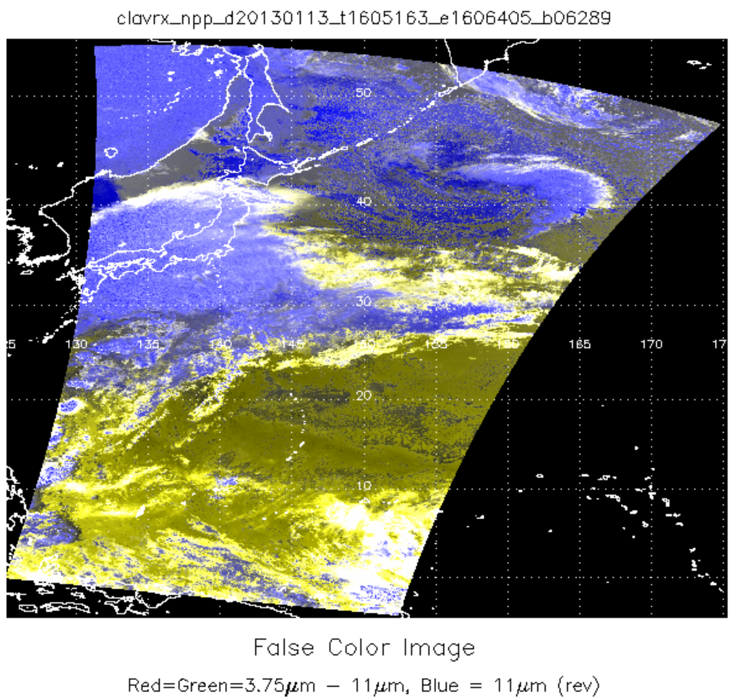
- The AWG Cloud Height Algorithm (ACHA) is an IR-only retrieval of Cloud-top Temperature, Cloud Emissivity and Cloud IR-microphysics.
  - Cloud-top height and pressure are derived from NWP profiles.
  - ACHA gives estimates of the effective altitude of a cloud that a satellite sees (can be deep into a thin cirrus layer)
  - ACHA is an O.E. and make uncertainties that have proven useful.
  - The performance of ACHA has been validated by comparing to the CALIPSO/CALIOP mission.
  - ACHA also makes IR optical properties (optical depth and particle size)

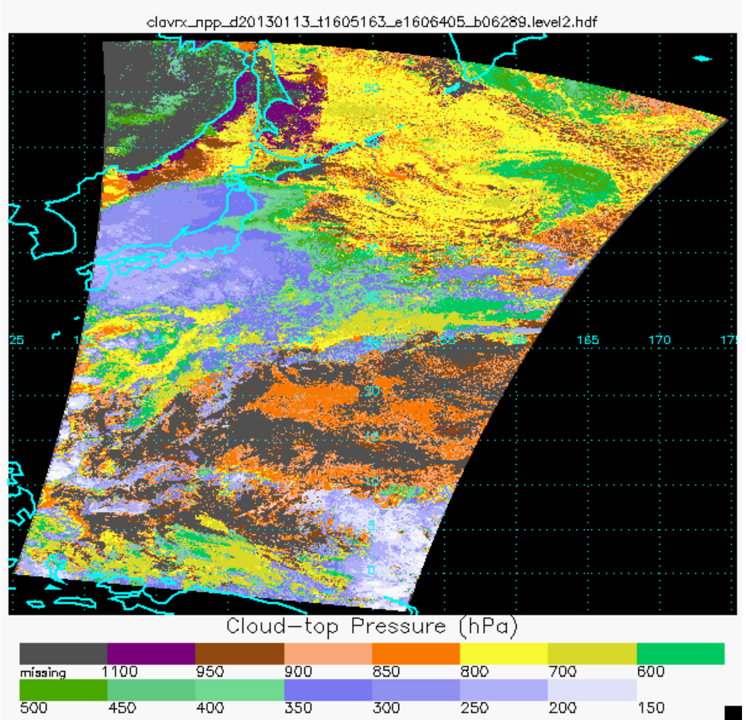
- Users
  - CTP is used by POLAR AMV Team
  - Sent to NWS/AWC and to Boeing
  - CTP is also used for cloud base and optical property retrievals

Current Operational Product

- Cloud Top Temperature, Emissivity and IR microphysics are output from the OE algorithm.
- Cloud Top Pressure and Height are inferred from matching NWP profiles. COD and CPS also made.
- ACHA is fast due to its use of analytical forward models.
- ACHA has the capability to run on 8 different modes. Each mode is a channel combination. Multiple modes can be run on each sensor. For example, VIIRS can be run with 11,12 μm or 8.5, 11 and 12 μm.

cirrus
low cloud
opaque Ice
clear ocean
clear land

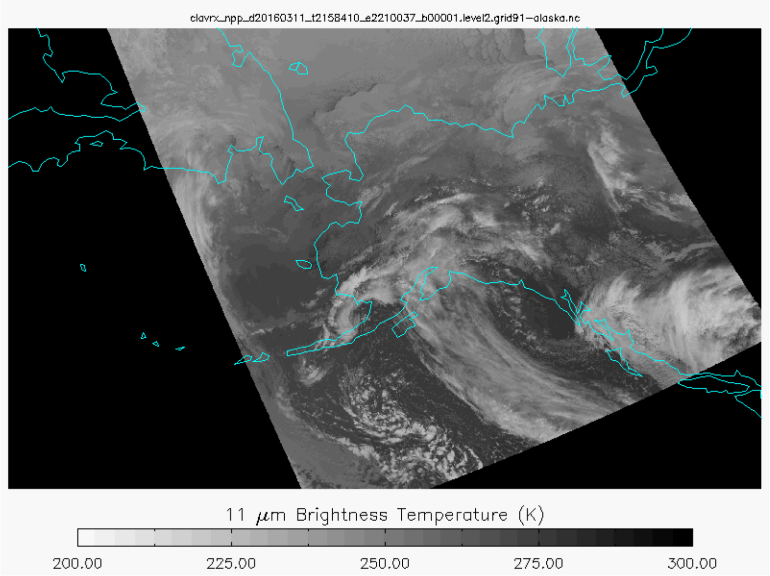


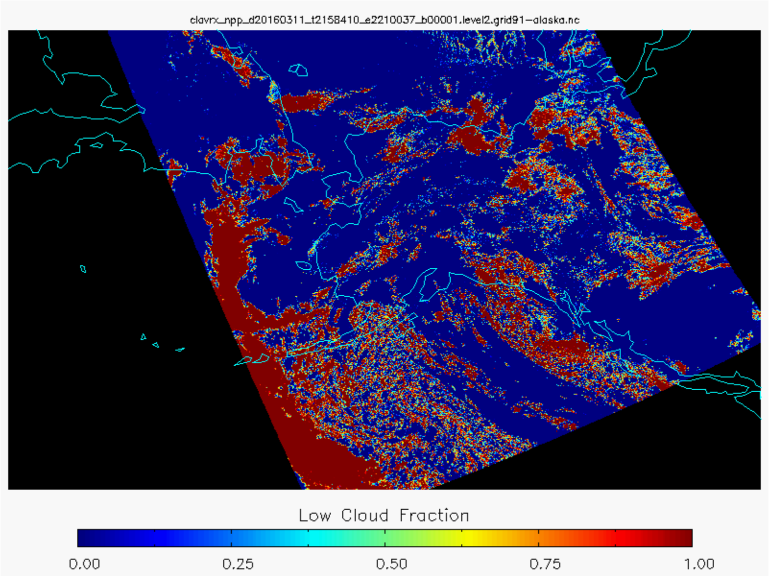


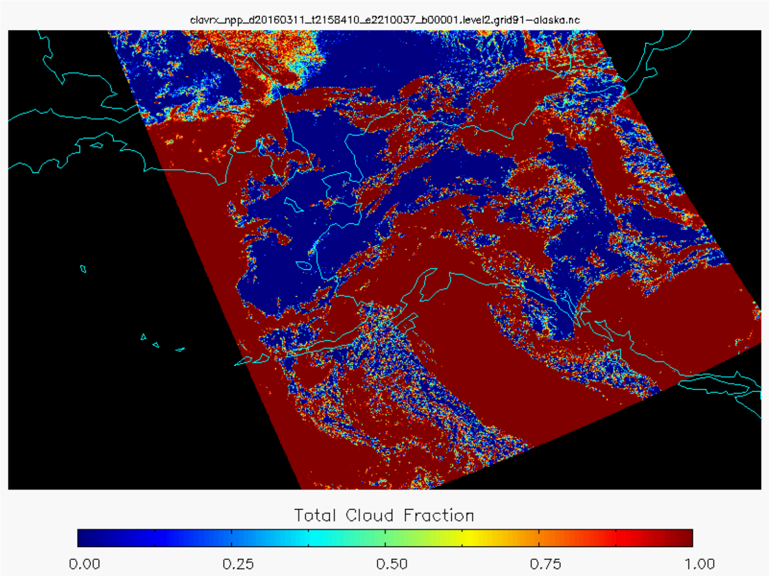
Nighttime VIIRS, 01/13/2013, 1551-1606 UTC

RTMA Cloud Cover Layers

- NCEP has requested we serve cloud products for the RTMA for the Alaska Domain (Grid 91)
- We are processing GINA DB data at CIMSS in real-time
- Mapping output to Grid 91 using MS2GT
- RTMA needs the total and layered cloud cover







Lessons Learned

- CALIPSO has revealed the complex cloud vertical structures. Assigning a single number for cloud height can be challenging.
- The selection of ice habit models can make a significant impact
- Correct identification of multi-layer clouds is critical in retrieval of upper layer ice cloud height.
- Absence of IR channels hurts ACHA but can mitigated by synergistic use of CrIS observations.

Path Forward

- Anticipated developments
  - Allowing ACHA to independently detect multiple layers.
  - New output of lower level CTP from the OE algorithm
  - New ice crystal single scattering property library including more habits for improving ice model
  - A version of ACHA exists that uses information from CrIS. Benefits warrant consideration for the operational product.
  - If J1 flies in formation with SNPP, would explore adding a temporal component (cloud top height growth/decay).
- Upcoming Deliveries/Reviews
  - ACHA passed the ARR.
  - We expect to update ACHA 2-3 times a year
  - Next delivery will be in summer 2016
- Risks
  - There is no known risk for J1

Summary

- ACHA has been fully implemented to NDE system
- ACHA products are being used by several groups but mainly from the geostationary imagers.
- We hope the Alaska RTMA applications proves successful.
- We need to canvass the CSPP LEO users and report their feedback.

Enterprise Cloud Base

Enterprise Cloud Base

- Summary of product
  - As part of the JPSS Cloud Cal/Val efforts, evaluation of the VIIRS IDPS CBH EDR showed it provided only marginal skill (Seaman et al. 2016, in prep).
  - CIRA team has developed a new statistical CBH algorithm constrained by CTH and CWP using A-Train satellites with support from CIMSS colleagues (Noh et al., 2016, in prep).
  - Validation using CloudSat shows the enterprise CBH algorithm outperforms the IDPS algorithm. The information is also used to modulate the layered cloud fraction (geometric thickness introduces additional cloud coverage at lower levels).
- Team members
  - CIRA team (Steve Miller, Y.J. Noh, John Forsythe, Curtis Seaman, Matt Rogers) and Dan Lindsey (STAR) in collaboration with Andy Heidinger (STAR) and Yue Li (CIMSS)
- Users
  - Operational users such as the Aviation Weather Center and the Alaska Region

Current Operational Product (I)

- Cloud geometric thickness is calculated from statistical relationships between observed CGT and CWP as a function of CTH which were built using A-Train satellites. CBH is calculated by subtracting CGT from CTH.
- An extinction method based on CALIPSO is employed for thin cirrus.
- The initial results applied to S-NPP VIIRS are promising.

Enterprise Cloud Base Data Flow

(Uppermost Layer)

Cloud Top Height (CTH)

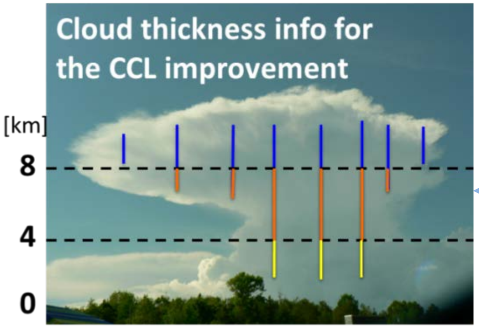
Cloud Water Path (CWP)
- CWP using COT and EPS from DCOMP or NLCOMP
- CWP from NWP as supplementary data

Appropriate cloud geometric thickness (CGT) regression

- Extinction method for thin cirrus (COT < 1)
- CBH=Condensation level from NWP for deep convective cloud

CBH retrieval

CBH = CTH - CGT



Improvement for lower layer cloud fractions

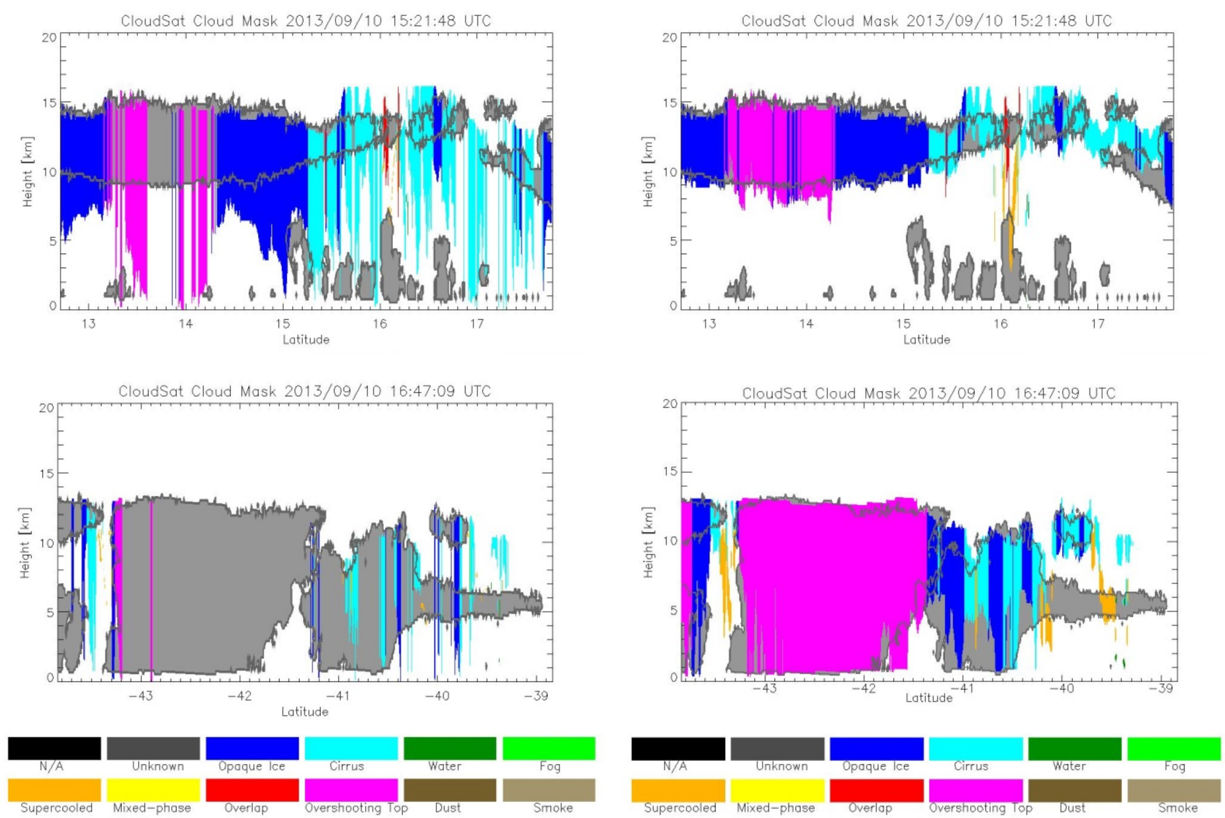
Current Operational Product (II)

- Matchups with CloudSat show the IDPS algorithm often fails to retrieve correct CBHs due to cloud phase/type-related CGT calculations and its dependency on numerous upstream cloud retrieval products .

The original IDPS with CLAVR-x input => Enterprise CBH

Arbitrary CGT changes due to cloud type changes →

Invalid CBH due to any missing upstream data often occurring for deep convective clouds →

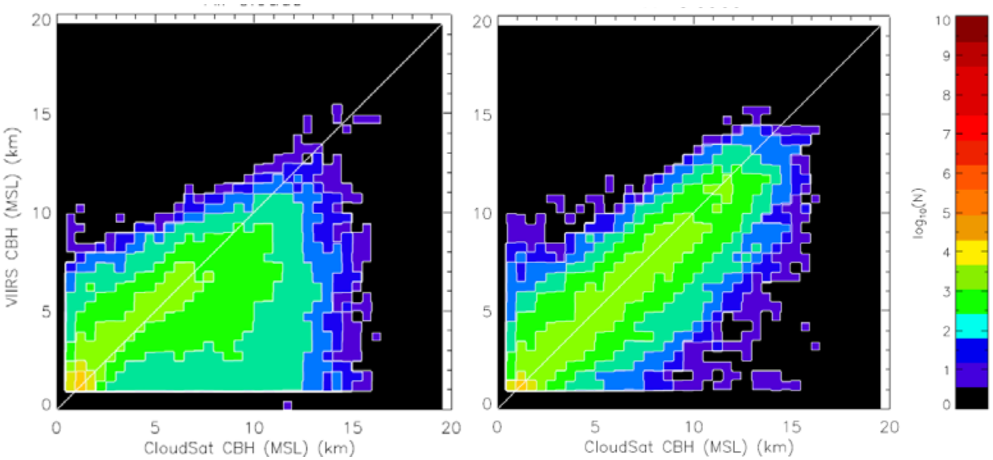


CloudSat Cloud Mask (gray-shaded) and VIIRS CTH/CBH (colored by cloud type)

Current Operational Product (III)

- Comparisons with CloudSat show the Enterprise CBH algorithm statistically outperforms the IDPS algorithm and shows better agreement in case-by-case examples. The new approach avoids errors arising from incorrect cloud type/phase retrievals which introduce large errors in the IDPS retrieval.
- The CBH information is used to improve the layered cloud fraction of middle and lower atmospheric clouds.

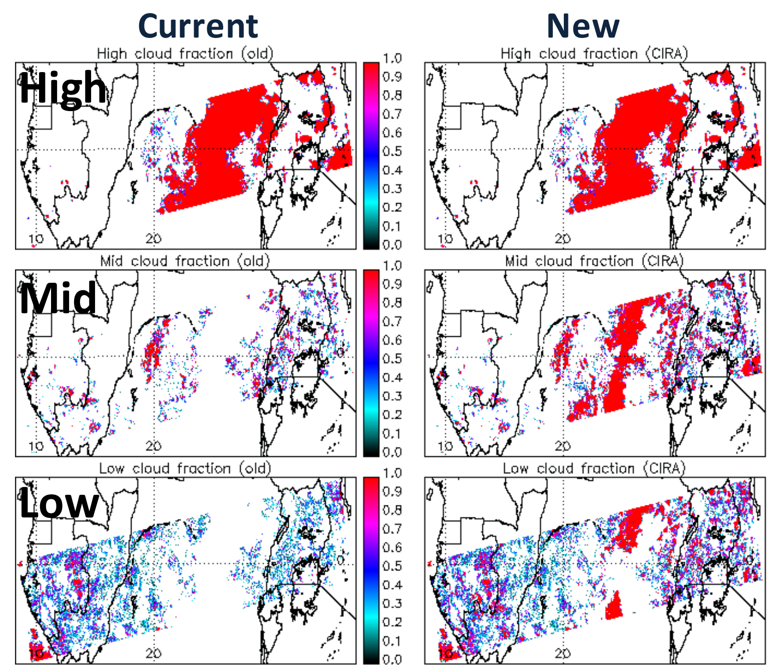
The orig. IDPS with NDE input **Enterprise CBH**



CBH [km]	Avg error	RMSE	Std of error	r^2
IDPS	0.7	2.7	2.6	0.45
Enterprise	0.3	1.7	1.7	0.79

82599 VIIRS-CloudSat matchup points for Sept-Oct 2013 when CTH is "within spec."

Layered cloud fraction changes using CBH



S-NPP VIIRS 20150511 (115841-120005 UTC)

Lessons Learned

- Implementation of product in NDE system
  - The first version of the CBH algorithm was delivered to the STAR Algorithm Implementation Team (AIT) in late February. CIRA and CIMSS teams will support the AIT in its correct operation and long-term monitoring within the operational NOAA Enterprise environment.
- Interdependency with other NDE products
  - The most critical upstream input for the Enterprise CBH retrieval is CTH and CWP (derived from COT and EPS). The accuracy of the CBH is directly proportional to the accuracy of CTH. The errors in CWP propagate to the cloud geometric thickness retrieval, and ultimately to the CBH estimate.

Path Forward

- Anticipated developments
  - Algorithm refinements to improve performance for
    - Deep convective clouds (convective core vs. opaque ice anvil stratification) using climatological data
    - Thin cirrus clouds using retrieved optical thickness and CloudSat/CALIPSO data for improved empirical fits
  - Improve the enterprise Cloud Cover/Layers product and validate the output using independent validation datasets.
- Upcoming Deliveries/Reviews
  - **The first version of the CBH algorithm was delivered to the STAR Algorithm Implementation Team (AIT). The Algorithm Theoretical Basis Document (ATBD) is being prepared**.
- Risks
  - Continue the quality control of the algorithm to assess any impact of J1 cloud upstream product changes from IDPS inputs.

Summary

- We have developed the Enterprise CBH algorithm based on statistical, semi-empirical, and model-fusion techniques relating cloud water path and cloud height to geometric thickness.
- **The results applied to S-NPP VIIRS are successful**. **Validation using CloudSat shows the enterprise CBH algorithm outperforms the IDPS algorithm**.
- The initial application using the CBH information for improvement of CCL layered cloud fractions is very encouraging, and a logical downstream application.
- The new algorithm demonstrated with VIIRS can be applied to other sensors (such as GOES-R ABI) which are able to retrieve CTH and CWP. We are beginning this evaluation in connection with GOES-R Risk Reduction activities.

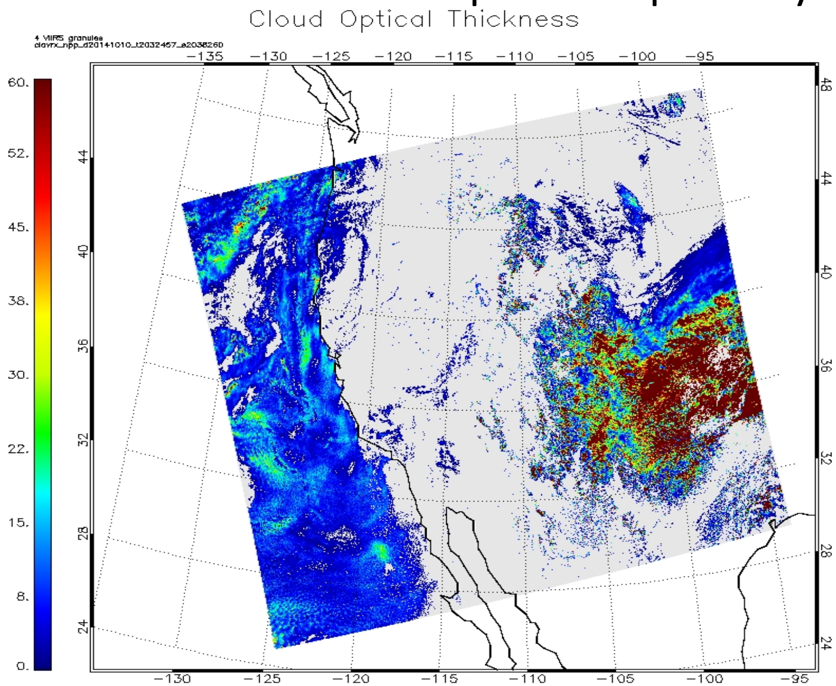
Daytime Cloud Optical and Microphysical Properties (DCOMP)

Cloud Microphysics Products for Enterprise

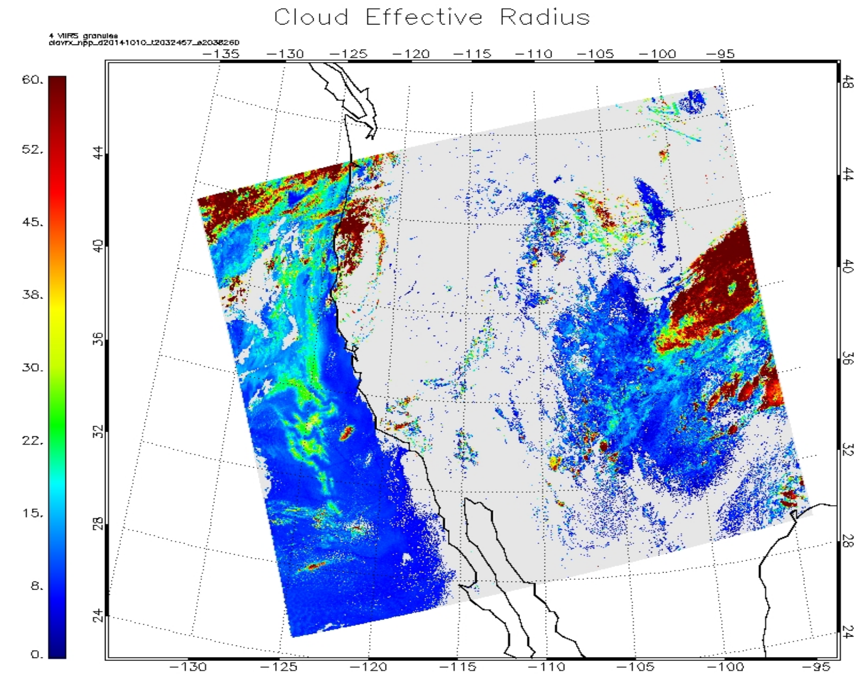
- DCOMP is the Enterprise retrievals for cloud microphysics.
  - DCOMP provides Cloud Optical Depth (COD) and Effective Cloud Particle Size (CPS) during daytime
  - COD and CPS are used to retrieve downstream products Cloud Water Path (CWP)
  - Products that are made internally are cloud transmission, albedo.
  - Experimental derived products include Precipitation and Icing threat.
  - NLCOMP is a new and unique retrieval and provides COD and CPS at night with sufficient lunar illumination
- Team members
  - Andi Walther, Andrew Heidinger, Steven Miller
- Users
  - Icing, Fog and other downstream applications
  - Geo products are used for solar insolation forecasting at DOE/NREL
  - Working with the JPSS Hydrology Initiative for other applications

Current Operational Product DCOMP

- Cloud Optical Thickness and Effective Radius are output from the DCMP OE algorithm.
- OE also provides physically-based uncertainty measurements of COD and REF which is based on uncertainty propagation from input and forward model uncertainty to product uncertainty.
- Cloud height products help to calculate atmospheric correction above cloud.
- Forward model is computed separately for ice and water cloud phase



Cloud optical thickness



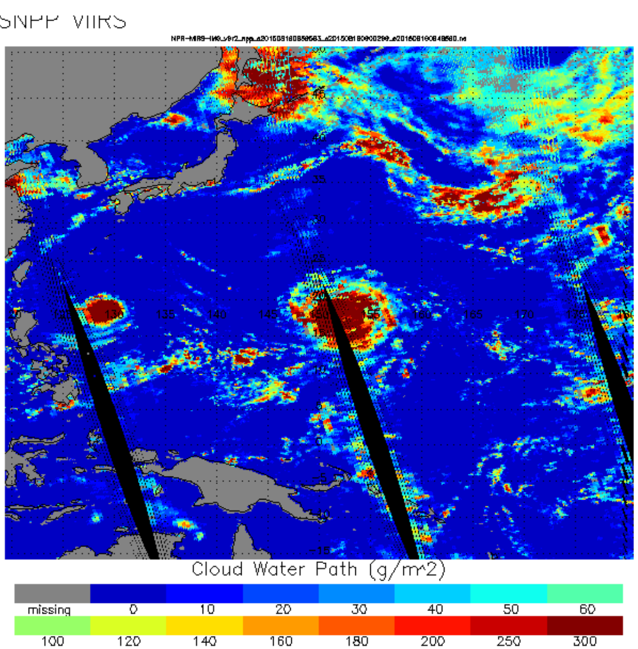
Cloud Effective Radius

Daytime VIIRS, 2014-10-10 20:32 UTC

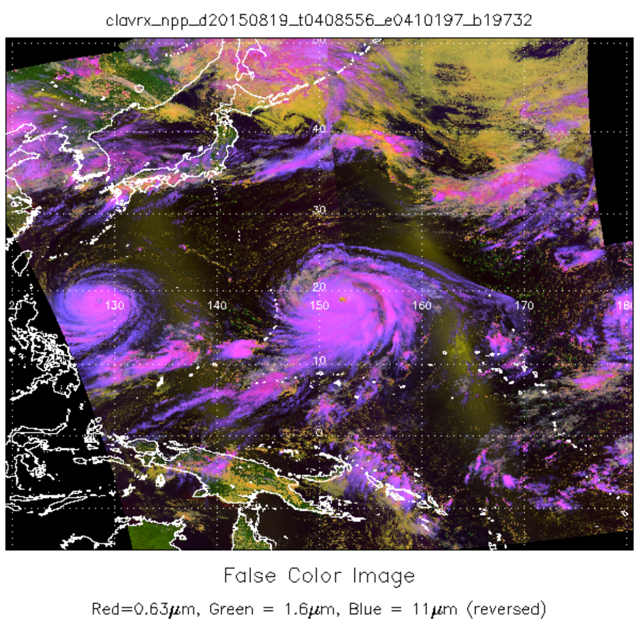
Other DCOMP Products

- Ice and Liquid Water Paths (LWP) derived from phase, optical depth and particle size.
- Solar transmission, albedo are automatically generated intermediate products (IPs)
- O.E. uncertainty estimates
- Synergy of VIIRS IWP and LWP with ATMS product is being looked at. VIIRS sees finer structures, ice clouds in general and clouds over land. ATMS sees water under ice and saturates at a much higher value.

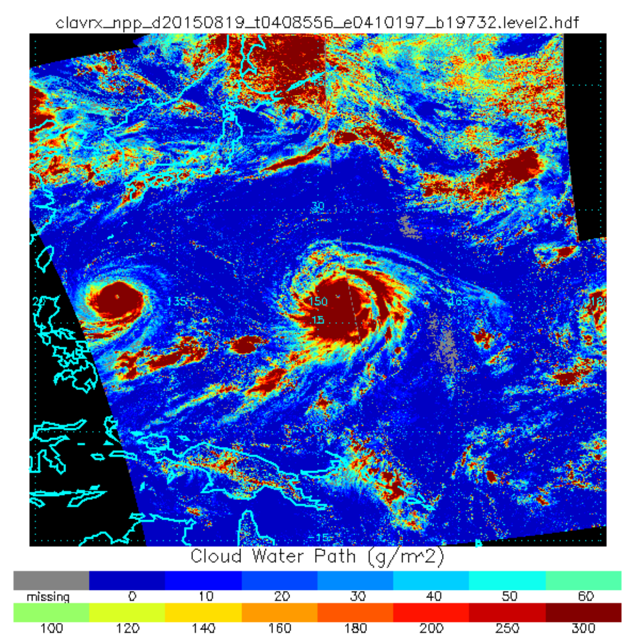
MIRS ATMS LWP



VIIRS False Color
ice cloud, water cloud



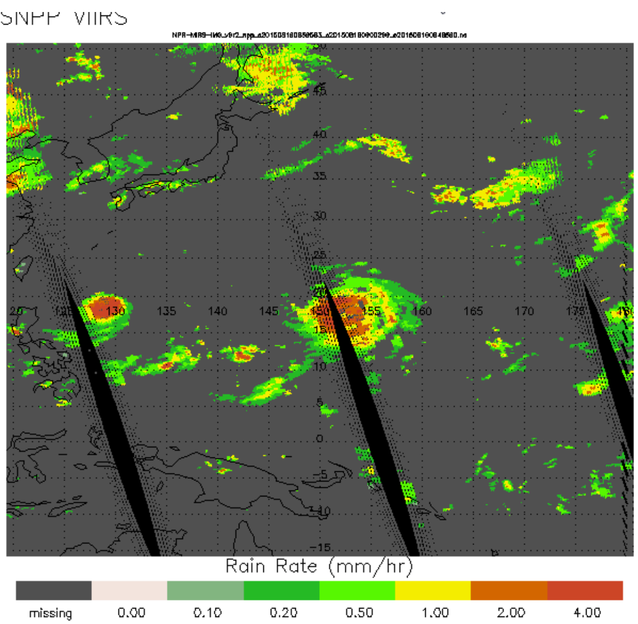
CLAVR-x- VIIRS CWP



Other DCOMP Products

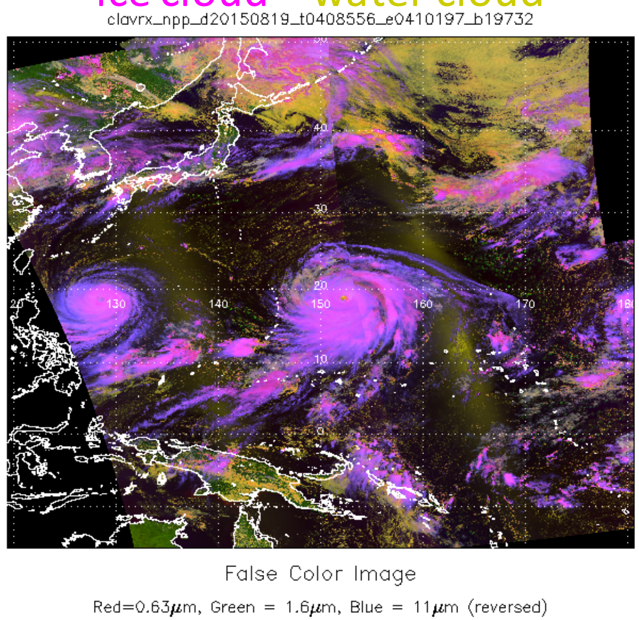
- Rain Rate can also be derived cloud properties (cloud water path, cloud particle size and cloud temperature) (Roebeling and Hollemann, 2011).
- We are exploring if the sub-set of precipitation from VIIRS cloud properties can complement that from the microwave instruments.
- At a minimum it offers qualitative validation of the cloud properties.
- VIIRS should offer more sensitivity to smaller amounts and finer structures.
- If this proves useful, this can be easily implemented in the Enterprise suite.

MIRS ATMS LWP

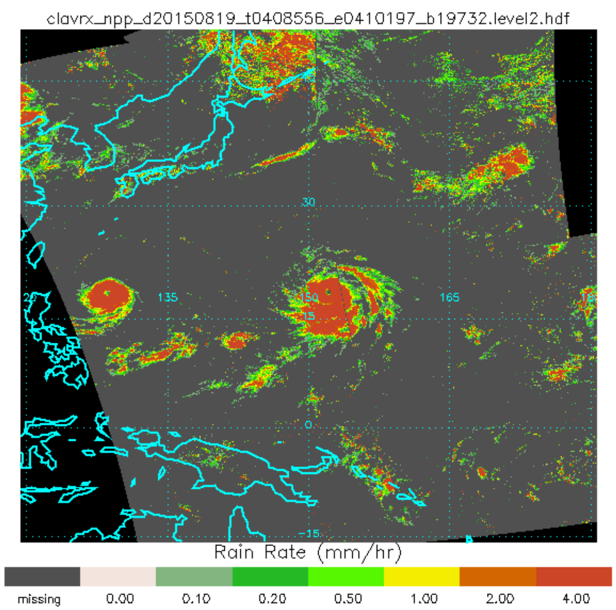


VIIRS False Color

ice cloud water cloud



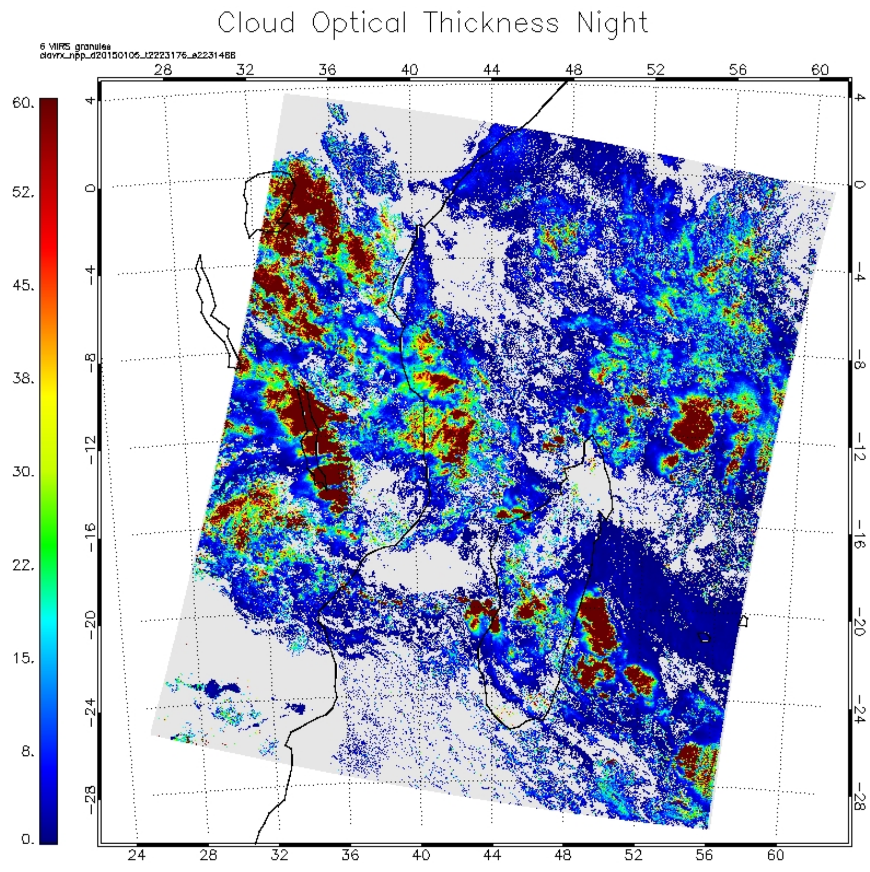
CLAVR-x- VIIRS LWP



Future Operational Products: NLCOMP

- Nighttime Lunar Cloud Optical and Microphysical Properties (NLCOMP) is the "lunar" analog to DCOMP.
- Under sufficient lunar illumination, NLCOMP can make the same products as DCOMP.
    - However, there are sets of conditions where the R_{eff} sensitivity vanishes.
- Algorithm uses same LUT structure as DCOMP.
- IR retrievals saturate for most clouds. NLCOMP brings daytime like performance with sufficient lunar illumination. (half moon or greater)
- Very beneficial for the high latitude regions in winter.

Nighttime VIIRS, 2014-10-10 07:49 UTC



Cloud optical thickness

Path Forward

- Anticipated developments
  - Implement existing development retrieval software to improve performance over permanent snow and seasonal snow into enterprise framework.
  - Check feasibility whether the use of multiple NIR channels could improve CPS performance.
  - Developments in cloud mask, cloud type and ACHA will also impact DCOMP/NLCOMP.
  - Future major development work will focus on applications, such as rain rate and icing threat retrievals.

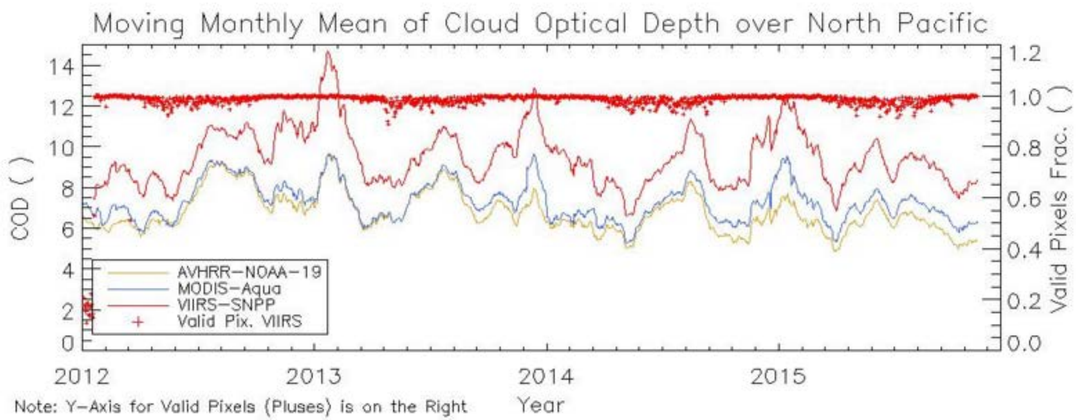
- Upcoming Deliveries/Reviews
  - We expect to update DCOMP and NLCOMP once a year
  - Next delivery will be in summer 2016.

- Risks
  - VIIRS calibration issues may impact specification compliance for thick clouds (see next slide)

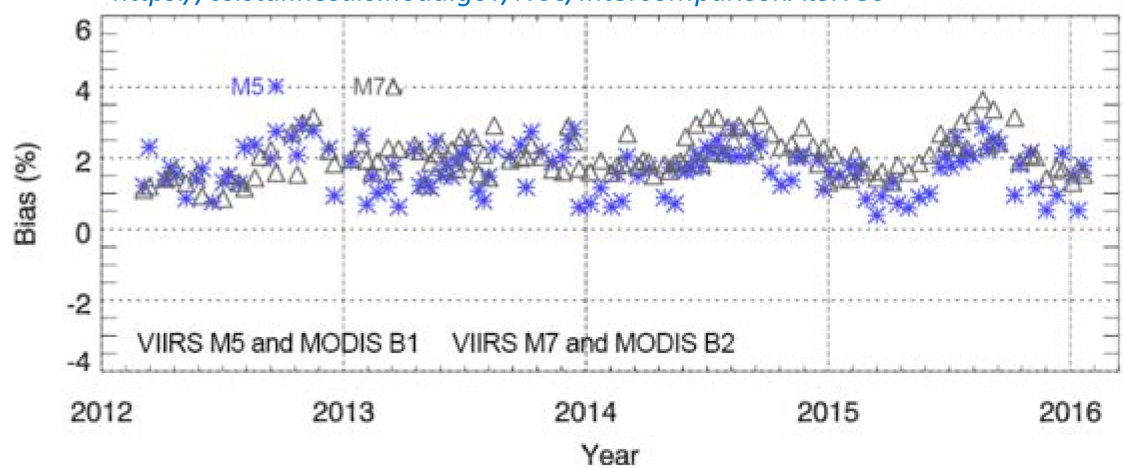
DCOMP Outstanding Issues

- M5 and M7 calibration issues.
- Our analysis (top) shows consistent Cld. Opt. Depth differences from MODIS and VIIRS. This could be caused by a calibration error of 2-3%.
- Similar to the current STAR JPSS Calibration Team analysis. (bottom)
- This has significant impacts on cloud optical properties and dependent applications.

VIIRS Cld Opt. Depth from M5 over a stratus dominated region compared to same algorithm applied to MODIS and AVHRR



Spectrally corrected comparisons of M5 and M7 to similar MODIS bands.
https://cs.star.nesdis.noaa.gov/NCC/IntercomparisonAtSNOs



DCOMP Summary

- DCOMP fully integrated into AIT SAPF on all relevant sensors.

- Working with JPSS Hydrology Initiative to explore use of the products in precipitation and icing threat.

- When the time is right, NLCOMP is available to the Enterprise Suite to bring daytime performance to the night.

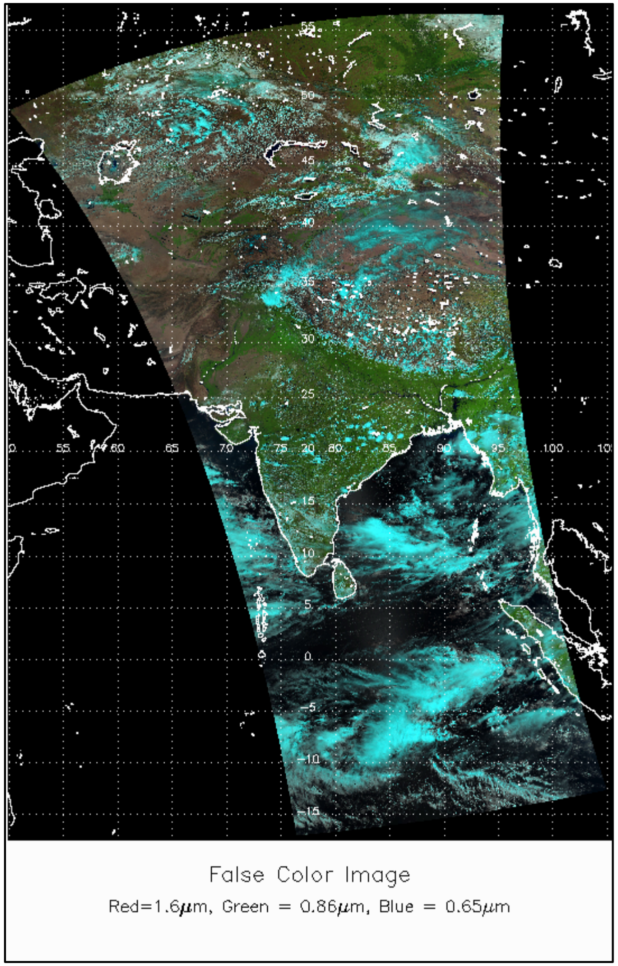
Summary and Conclusions

Final Summary

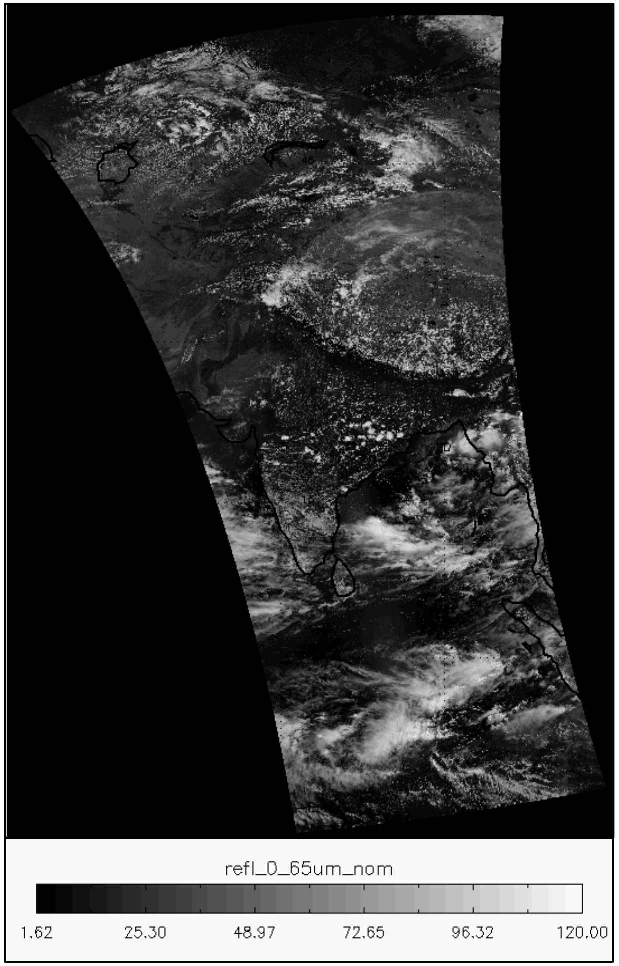
- Cloud algorithms are nearly fully available from AIT SAPF.
- Cloud Mask interaction is sought and please chat with Tom Kopp if you have time.
- VIIRS M5 and M7 Calibration are still off relative to MODIS and this impacts our consistency across the “Enterprise” sensor suite.
- Several new developments should be available by JPSS-1 (NLCOMP, DNB Cloud Mask, +CrIS).
- We look forward to full operational capability soon.

Thank You!
Backup Material Follows

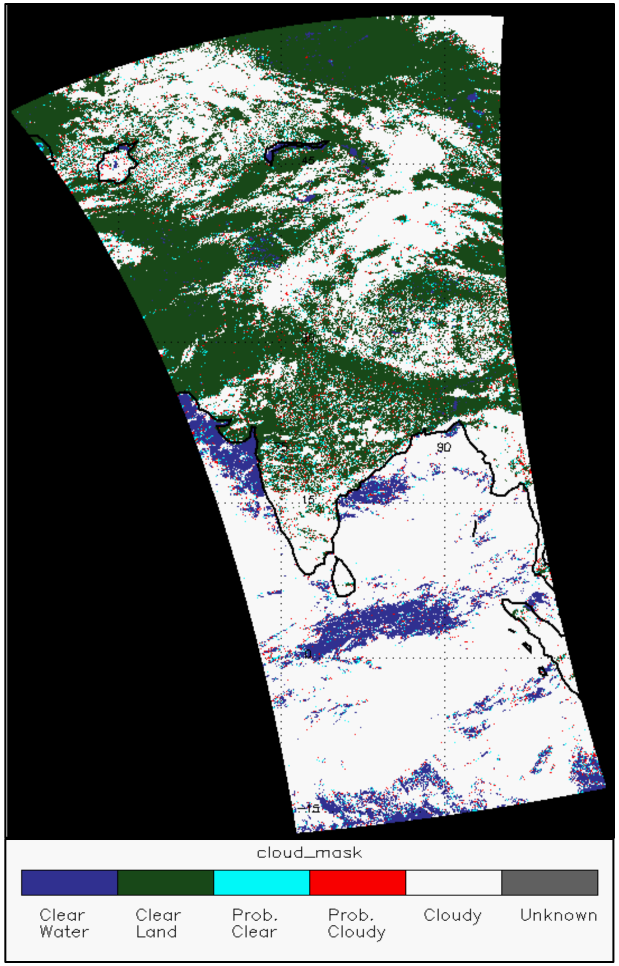
Current Operational Product



Natural Color RGB



0.65 μm Reflectance



Cloud Mask

Daytime VIIRS, 2013-09-13 07:49 UTC