CM SAF Climate Monitoring

SMHI

Cloud Masking in Passive Imagery: Recent Advancements and Assessments Utilising CALIPSO-CALIOP Data

Karl-Göran Karlsson
SMHI

Keynote presentation at ICWG-2
Madison, Wisconsin, USA
31 October 2018

Outline:

- Motivation: Why do we need cloud screening?
- What is required for a successful cloud screening?
- Short historic reflection over how methods have been introduced and how they have evolved
- CALIPSO-CALIOP data: Boosting the development of cloud masking methods
- Validation principles, uncertainty and associated problems
- Outlook: New approaches

Is it still important to know whether a pixel is clear or cloudy in retrieval applications?

Yes:

- Surface parameter retrievals need radiances free from cloud-contamination
- NWP data assimilation (and modelling) need to separate cloud-free from cloudy radiances
- Climate monitoring applications are interested in the cloud radiative effects (“cloud forcing”, “cloud feedback”)

Will this need still remain in the future?

Yes but…

- information needs to be more quantitative (i.e., exactly what clouds are detected and what is the uncertainty?)
- more focus on cloud properties
- there will probably come a time when the distinction cloudy/cloud-free is not so important anymore (e.g., because of new treatment of cloudiness in NWP models and foreseen continuous assimilation of all radiances)

What is required for cloud screening to become successful?

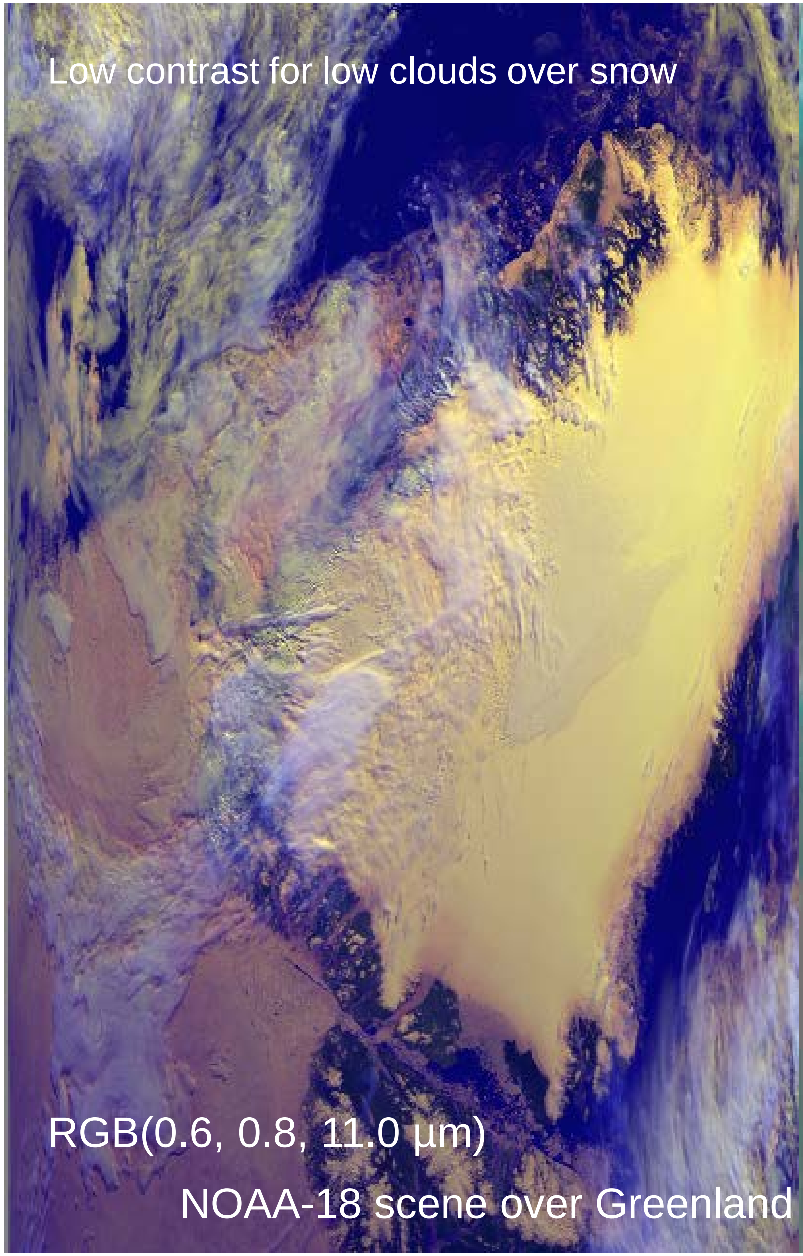
Contrast, contrast, contrast……!

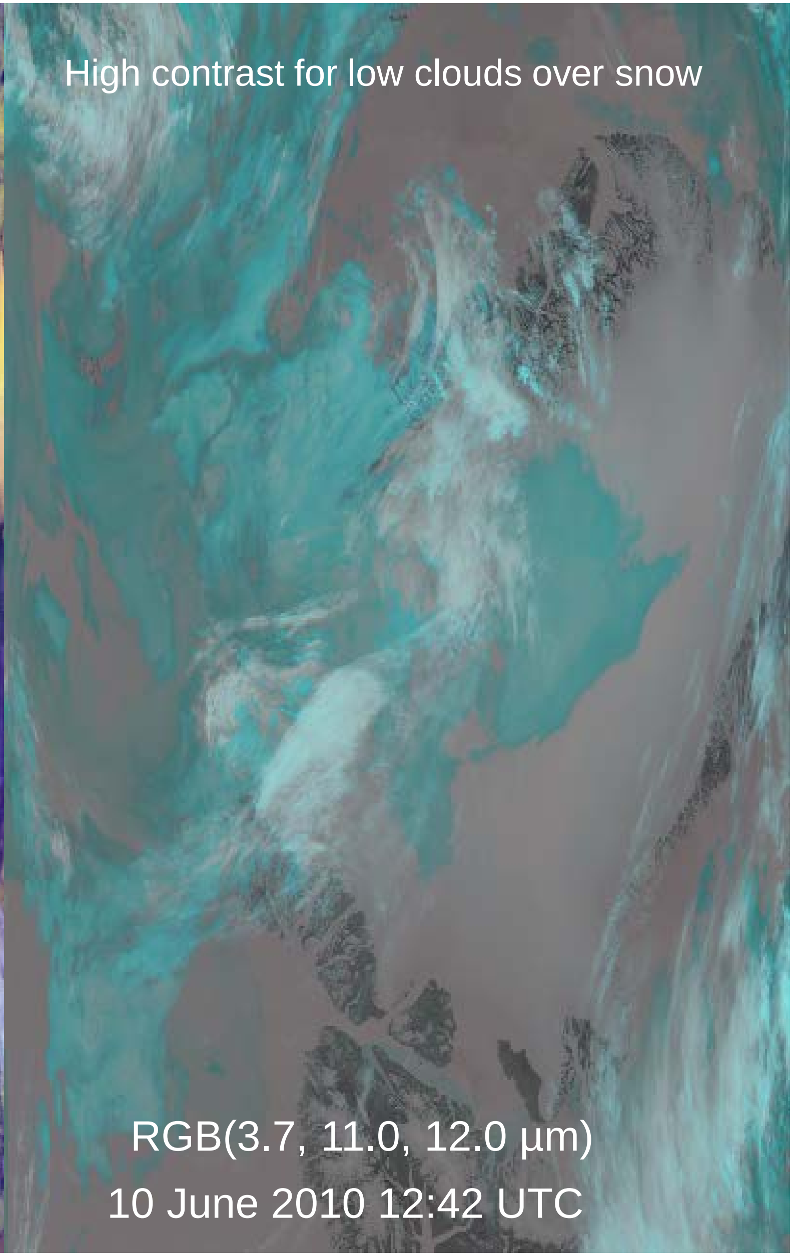
➔ If cloudy radiances are not different from the cloud-free radiances there will be no skill in detection!

➔ CONTRAST IS THE DIFFERENCE IN LUMINANCE OR COLOUR THAT MAKES AN OBJECT (OR ITS REPRESENTATION IN AN IMAGE OR DISPLAY) DISTINGUISHABLE. IN VISUAL PERCEPTION OF THE REAL WORLD, CONTRAST IS DETERMINED BY THE DIFFERENCE IN THE COLOR AND BRIGHTNESS OF THE OBJECT AND OTHER OBJECTS WITHIN THE SAME FIELD OF VIEW.

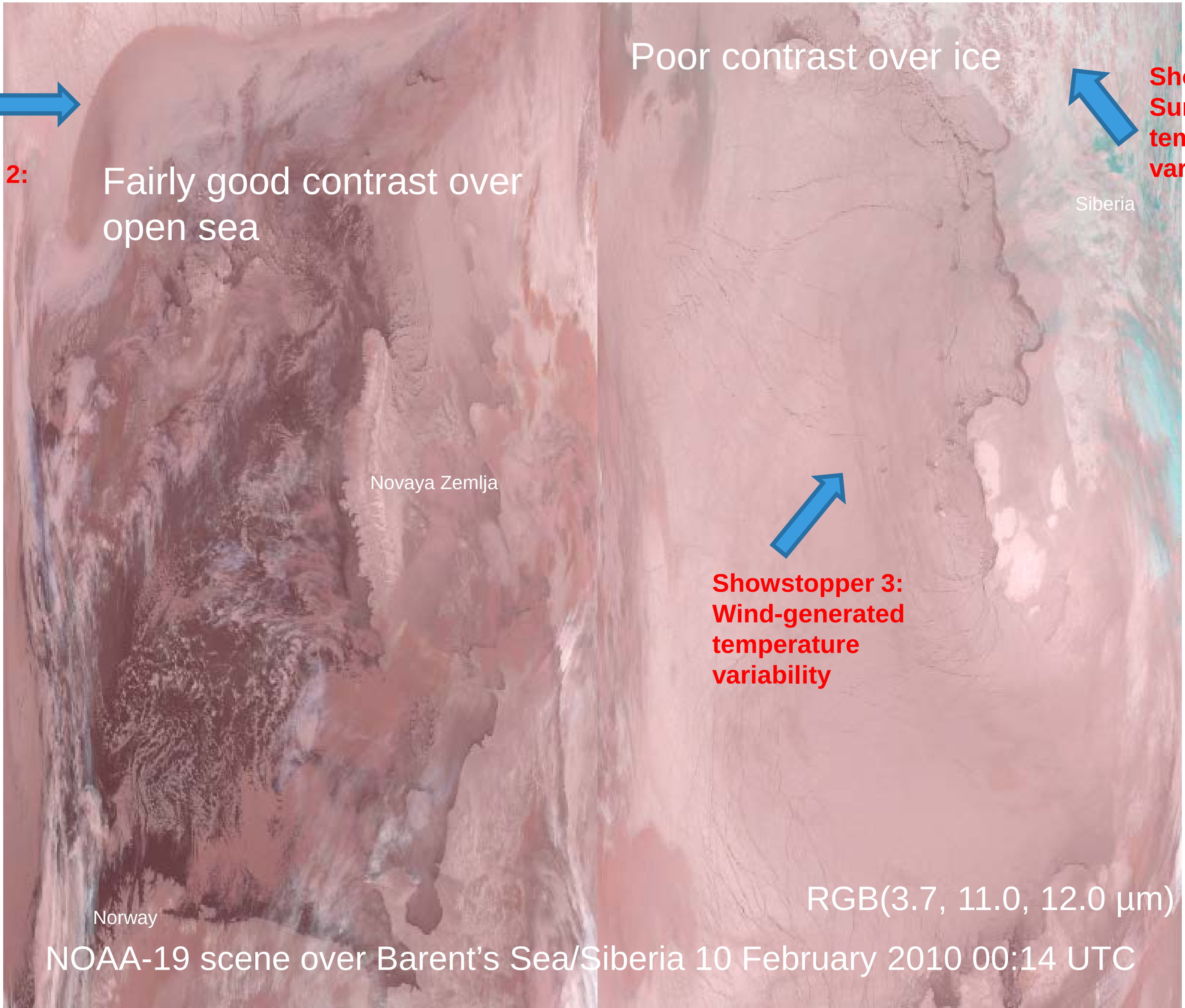
(from Wikipedia)

AVHRR GAC over Greenland





Polar night AVHRR GAC over the Arctic



Showstopper 1: Surface temperature variability

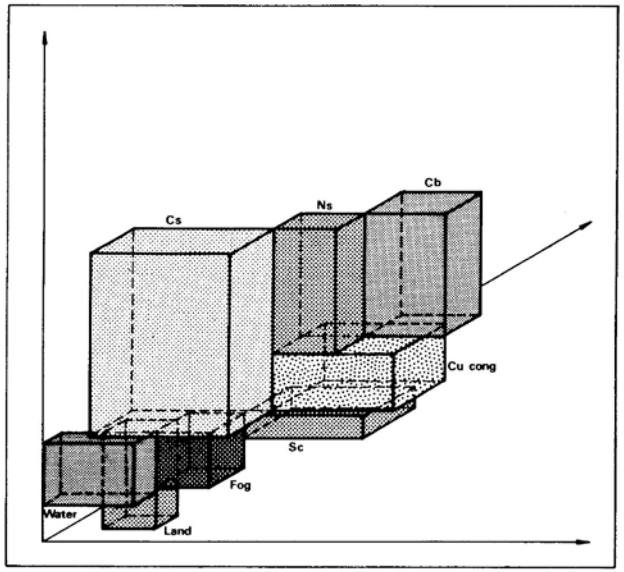
Showstopper 2: Mixed cloud phases

Showstopper 3: Wind-generated temperature variability

CM SAF Climate Monitoring

SMHI

Multispectral thresholding: A long-living beast!



ANALYS AV MOLN OCH NEDERBÖRD GENOM AUTOMATISK KLASSNING AV AVHRR DATA

av Erik Liljas

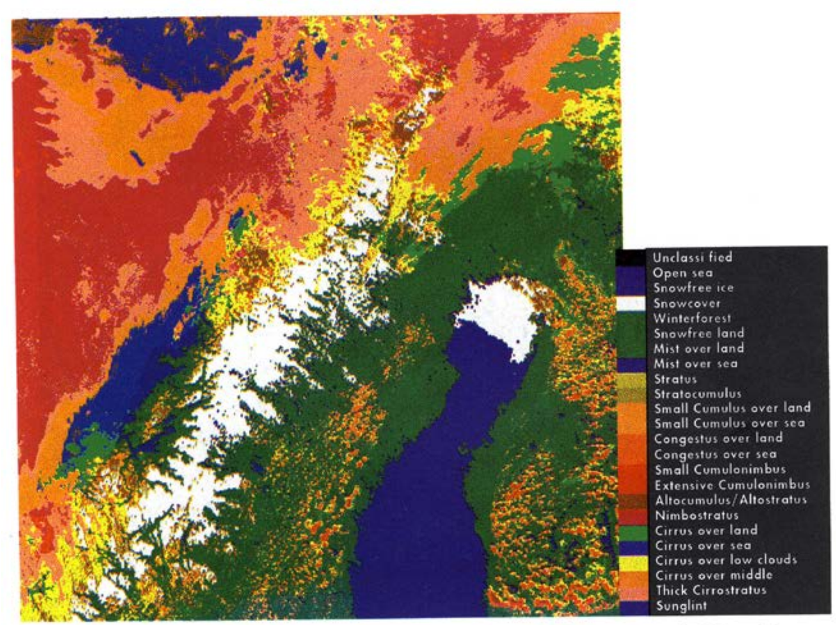


Figure 9. SCANDIA cloud classification for the same AVHRR scene as in Figure 8.

Visualization of a three-channel Box Classification of AVHRR data – the first step towards quantitative applications (introduced by E. Liljas 1979)

Example of SCANDIA box classification from 1990 - thresholds defined as functions of illumination, viewing geometry and temperature profiles

Multispectral thresholding:

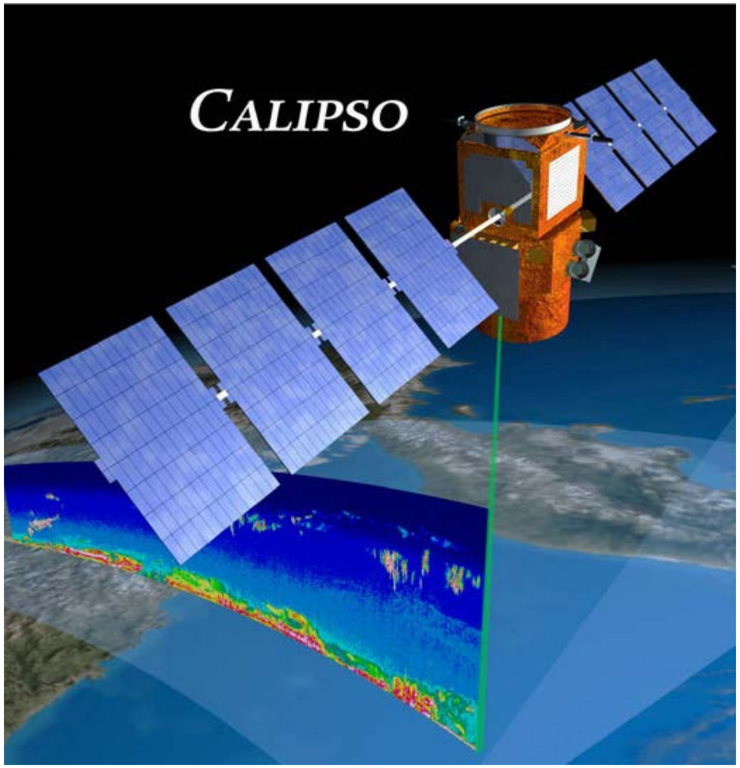
Still used today but with thresholds dynamically adjusted or made more ”fuzzy”. Examples:

- Several EUMETSAT applications (e.g., NWC SAF PPS/MSG schemes and general cloud screening tool at Central Facility)
- MODIS cloud masking

Reasons for long life:

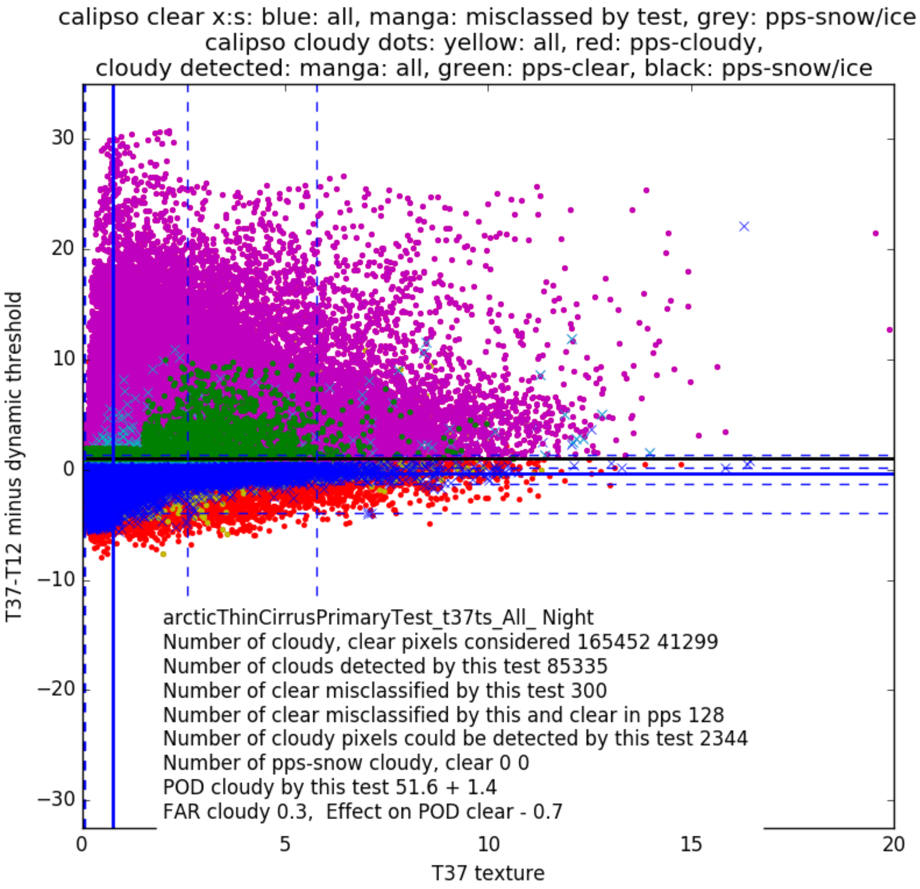
- Flexible adaptations possible (e.g., simply skip or add some tests depending on conditions).
  This is hard to realise for parametric or statistical solutions. The latter depend on access to homogeneous training datasets.

Access to CALIPSO cloud lidar CALIOP – a new era for cloud masking development!



- Direct detection of cloud particles
- Superior sensitivity compared passive imagery
- Accurate cloud top height determination
- Allowing estimation of cloud optical thicknesses and cloud phase
- Allowing simultaneous observations with passive sensors
- ”Global” coverage
- Surprisingly long availability (now 12+ years)

New ways of testing and validating the use of various thresholds
– example from PPS 2014/CLARA-A2/PPS 2018 development

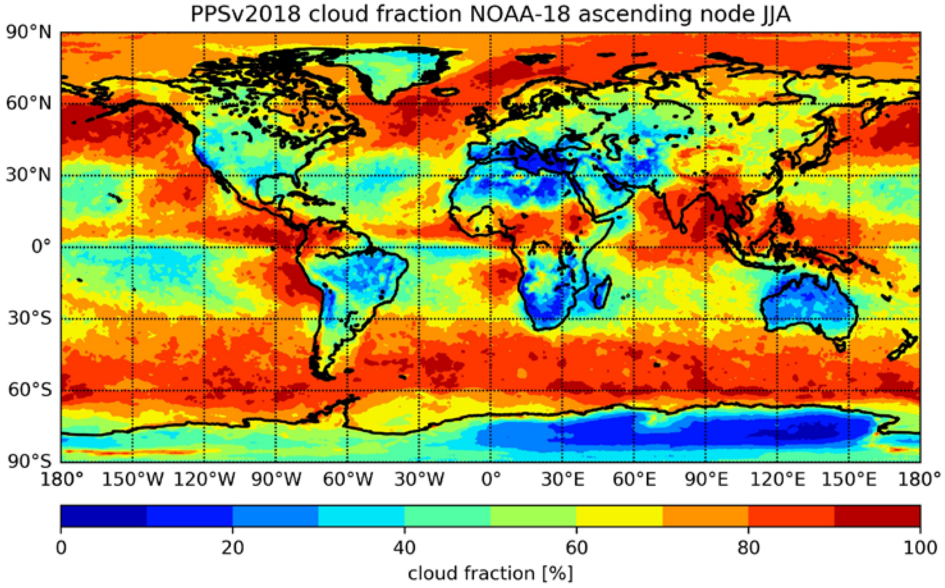


Courtesy of Nina Håkansson

Learning from validation

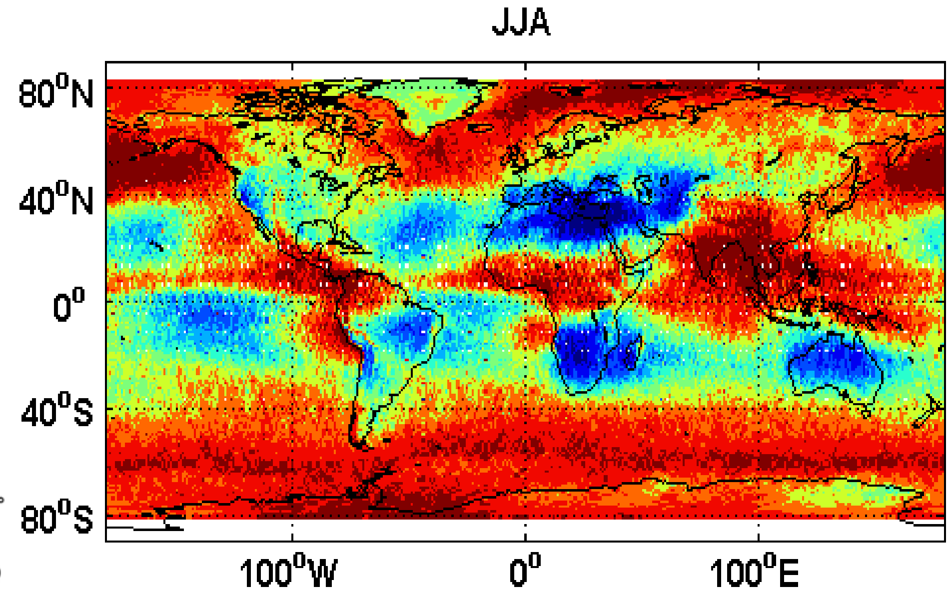
Minimizing false cloud occurrence over polar areas
➔ large seasonal variation in CLARA-A2/PPS polar cloud amounts

Mean PPS 2018 cloudiness from all collocated NOAA-18 -CALIPSO scenes 2006-2015



Courtesy of Jan Musial

Mean cloudiness from all CALIPSO orbits 2006-2015 (CLAY 4.10)



Courtesy of Abhay Devasthale

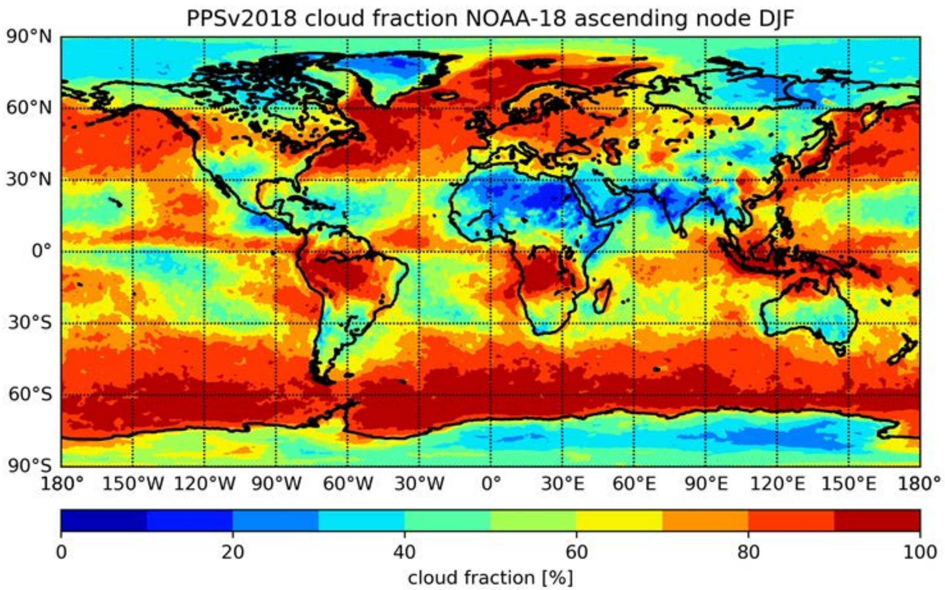
Northern Hemisphere Summer

Learning from validation

Minimizing false cloud occurrence over polar areas

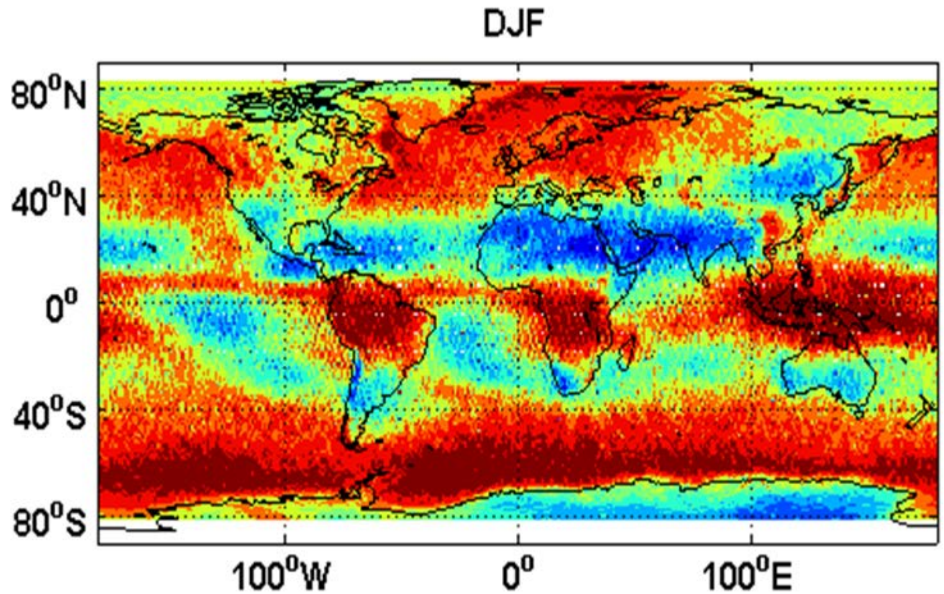
➔ large seasonal variation in CLARA-A2/PPS polar cloud amounts

Mean PPS 2018 cloudiness from all collocated NOAA-18 -CALIPSO scenes 2006-2015



Courtesy of Jan Musial

Mean cloudiness from all CALIPSO orbits 2006-2015 (CLAY 4.10)



Courtesy of Abhay Devasthale

Northern Hemisphere Winter

Further quantification of accuracies and capabilities using simultaneous observation (SNO) approach

GOALS:

- To perform detailed validation of results (i.e., addressing different geographic, illumination and surface conditions)

- Take into account the differences in sensitivity between CALIOP and AVHRR observations (i.e., use CALIOP information about cloud optical thickness)

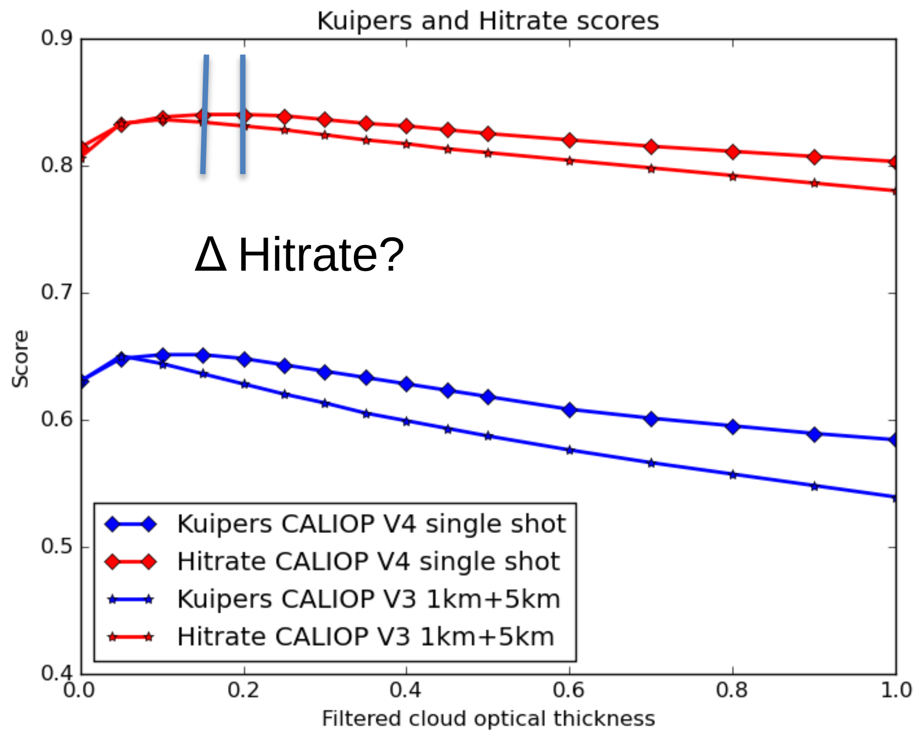
- Quantify the meaning of the cloud mask:
  For example, when a probabilistic classifier suggests 50 % probability that it is cloudy, what does it really mean? 50 % probability of any cloud?

  ➔ We need to give additional information specifying which clouds we mean!

  Otherwise the information cannot be used quantitatively (e.g. in COSP simulators).

The advantage of CALIOP-estimated cloud optical thicknesses (5 km)

Introducing the concept of using successively shrinked CALIOP cloud masks and the meaning of peak Hitrate



$$\mathrm{HR} = \frac{a+d}{a+b+c+d}$$

a: Correctly cloud-free

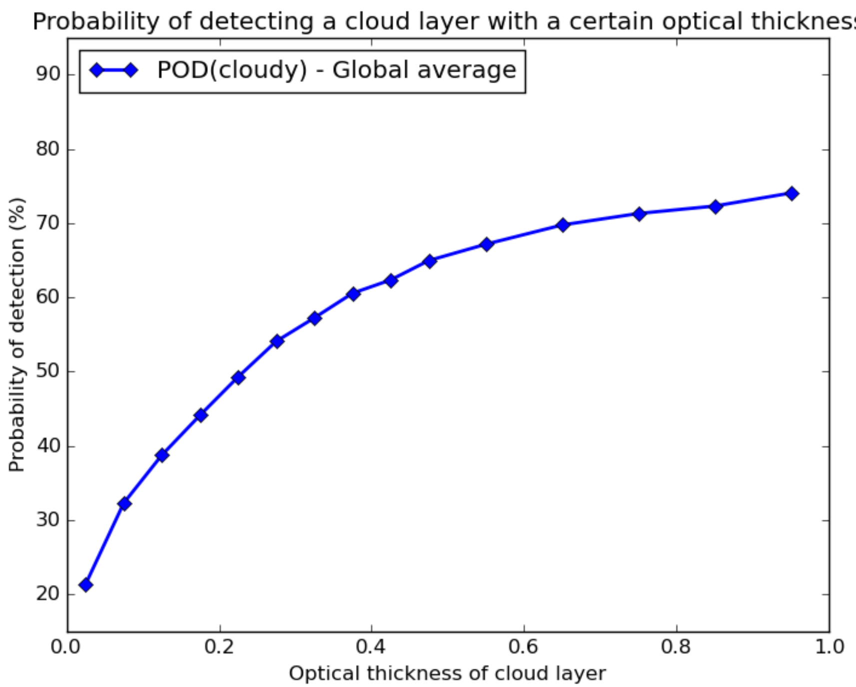
d: Correctly cloudy

Interpretation:

- If Δ Hitrate = 0 we are at the peak. But it also means that for clouds being exclusively in the studied finite interval we **detect 50 %** of them (see definition of Hitrate)!!! ➔ We can estimate at which cloud optical thickness that we detect 50 % of them!

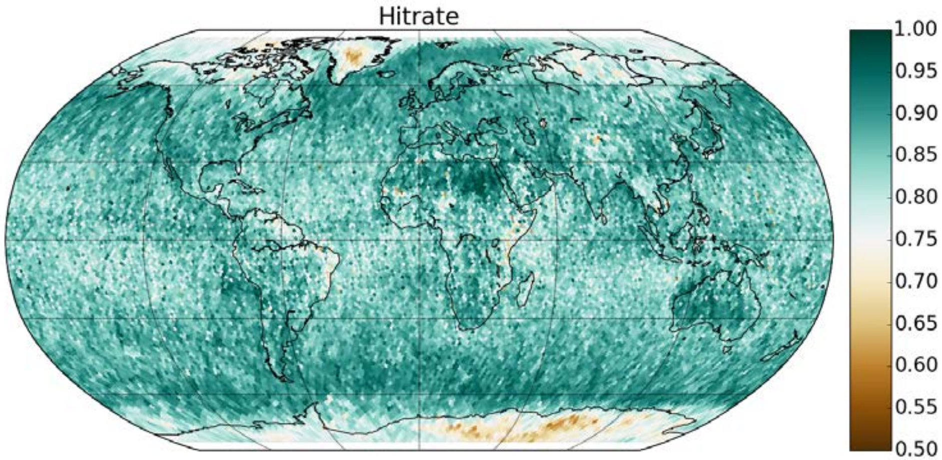
An interesting consequence of this: If going through each finite interval we may estimate the probability of detection as a function of cloud optical thickness.

This is the result based on all available global matchups between CALIPSO and CLARA-A2 (PPS 2014+) in the period 2006-2009:

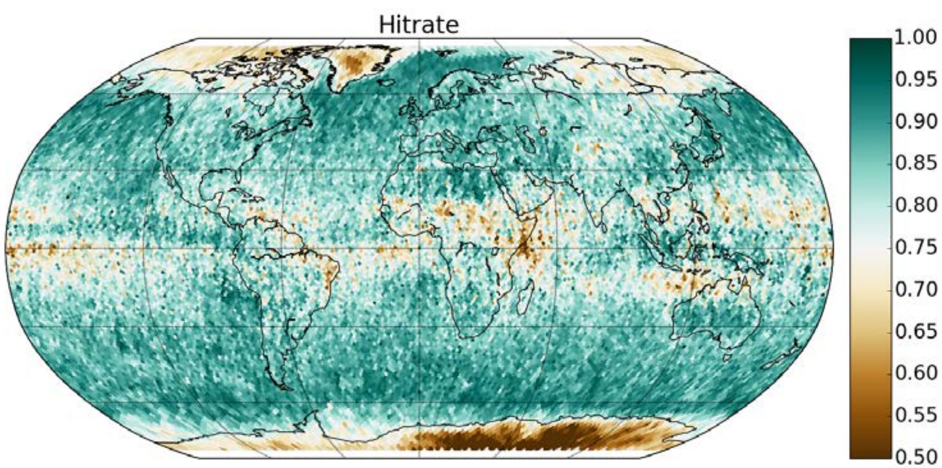


Conclusion: As a global mean the CLARA-A2 **Cloud Detection Sensitivity** (= 50 % detection) is found at an cloud optical thickness of 0.225!

Maximum Hitrate for CLARA-A2 results is achieved if comparing with a CALIOP cloud mask filtered at cloud optical thickness 0.225.

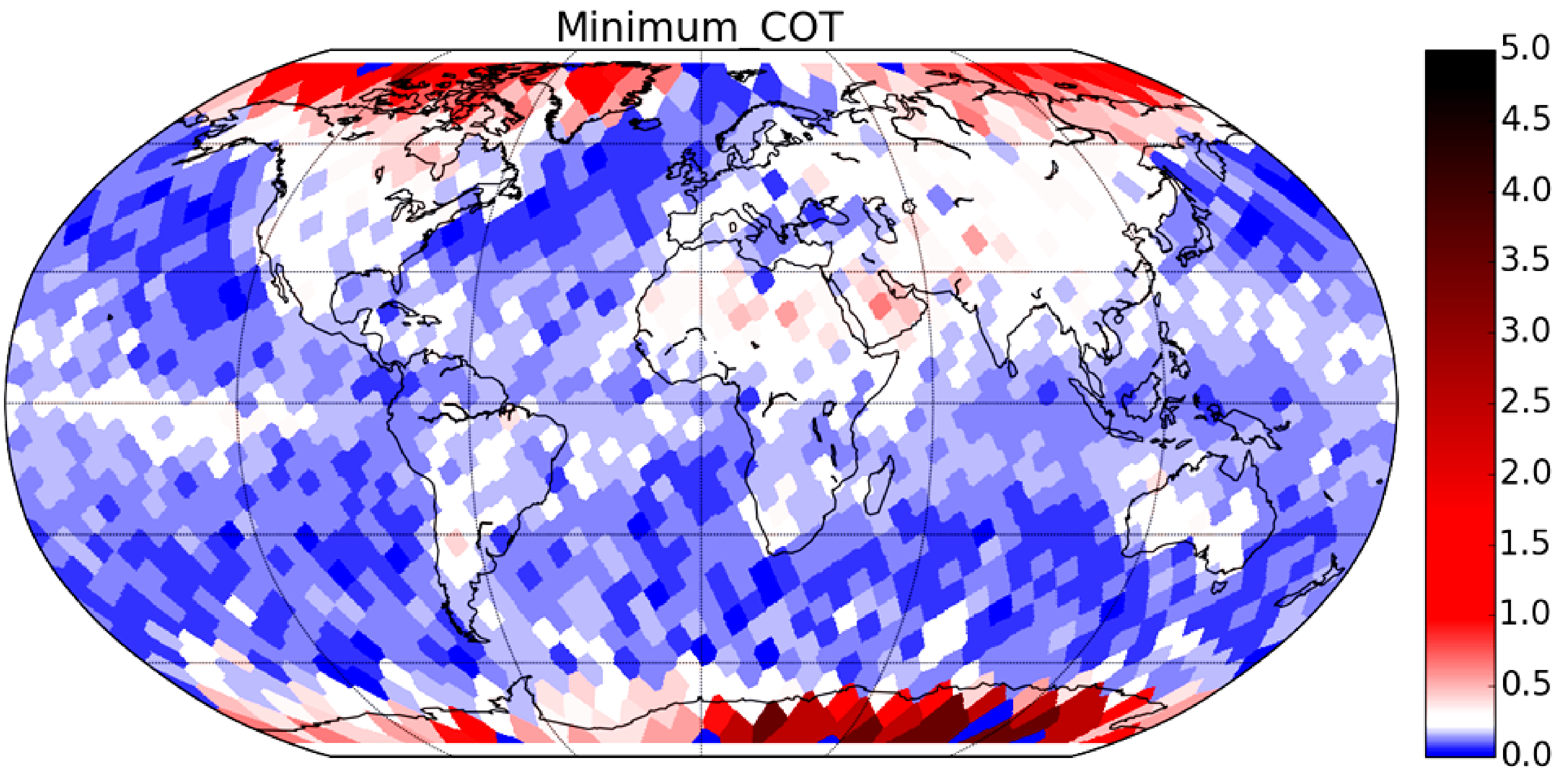


Filtered at 0.225



No filtering

But the globally averaged Cloud Detection Sensitivity is largely misleading! The geographical variation is remarkably high. With enough of matchups the global variation can be estimated (here in a grid resolution of 300 km)



Global variation of **Cloud Detection Sensitivity** (= 50 % detection) for the CLARA-A2 cloud CDR expressed in minimum cloud optical thickness. Colour table shows values better than the global mean (0.225) in blue colors and values worse than the global mean in red colours.

(from Karlsson and Håkansson, AMT, 2018)

So, we are able to complement our validation results with information on the globally varying cloud detection efficiency.

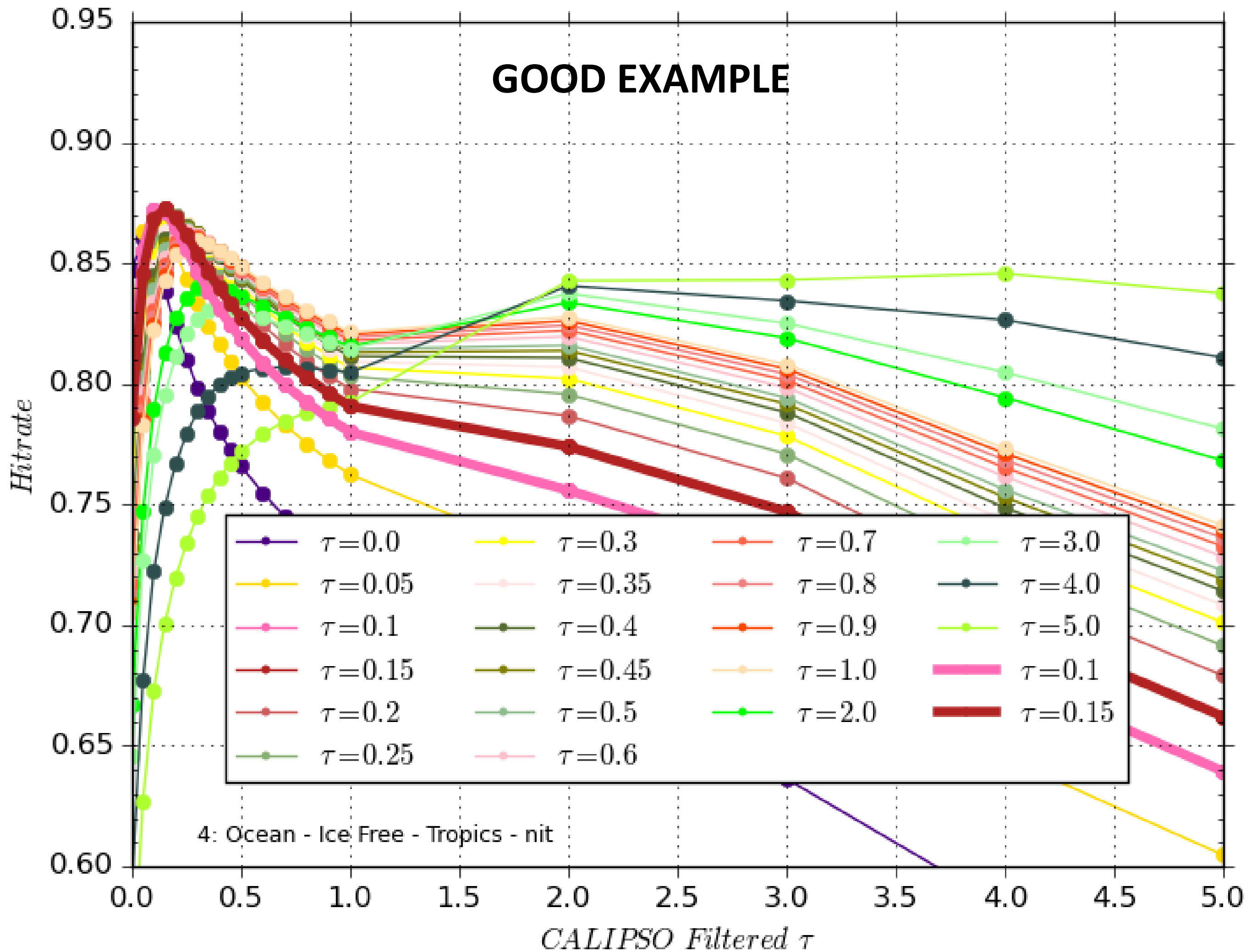
But can we utilize this tool when training a method for specifying the meaning of the suggested cloud mask output (e.g. probabilities)?

Yes, we can check which of the restricted CALIOP cloud masks that is best reproduced by our cloud mask

→ Set the constraint that peak in Hit Rate shall occur at the same optical thickness that was used when training!

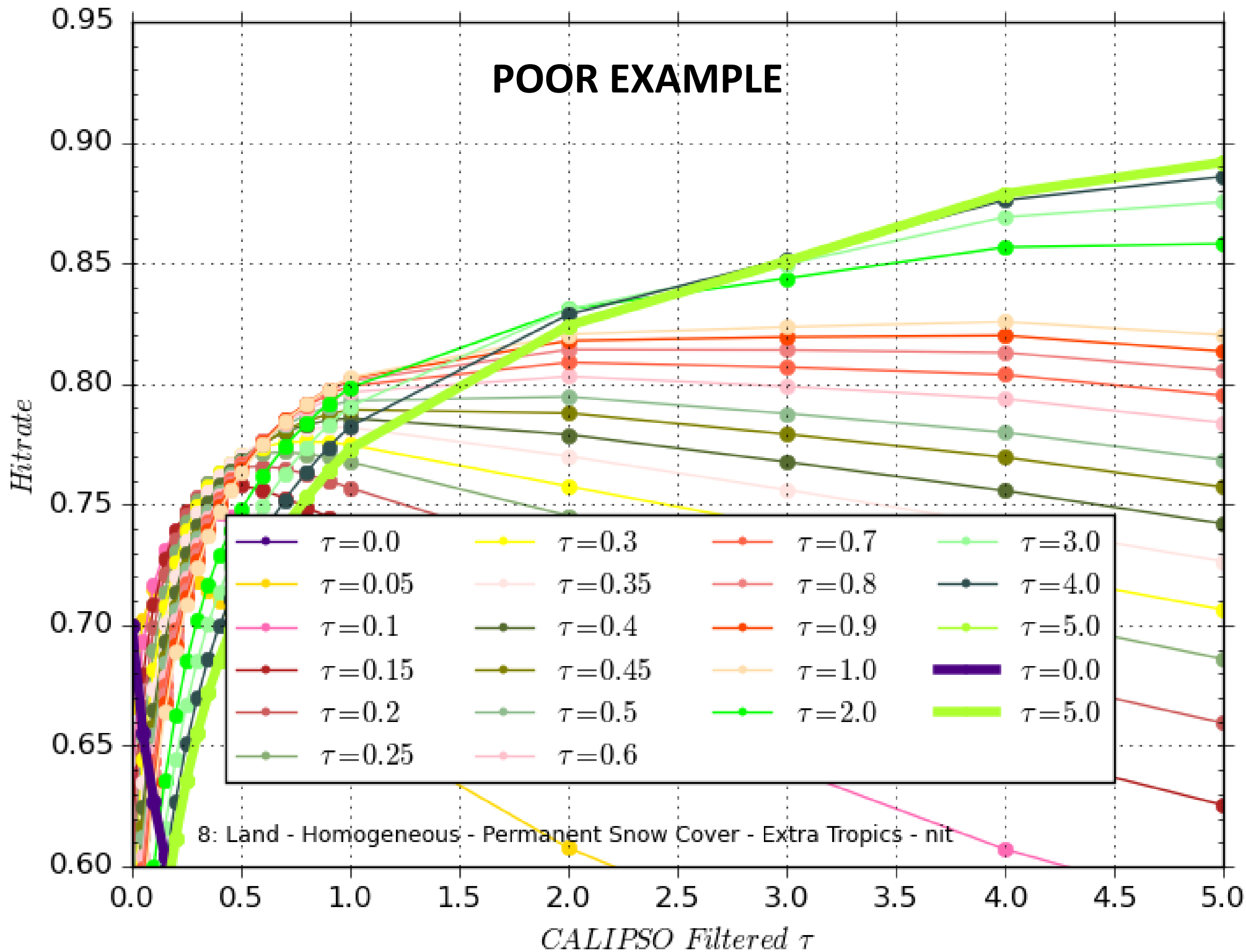
Examples will be given for PPS 2018 CMAPROB method

Finding peak Hit Rate for the same filtered optical thickness as the restricted CALIOP cloud mask used during training: Results over tropical ocean at night



The winner is: **CALIOP cloud mask filtered at optical thickness 0.1!**

Finding peak Hit Rate for the same filtered optical thickness as the restricted CALIOP cloud mask used during training: Results over snow at night



The winner is: ??? ….maybe optical thickness 2.0 as a compromise???

Suggested optimal trained CALIPSO cloud masks for various surfaces

(final for CMAPROB in official PPS 2018 release)

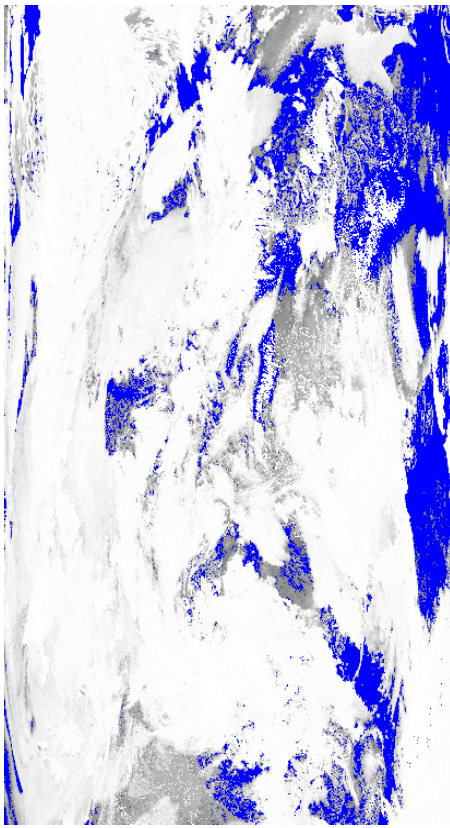
Surface category	DAY	NIGHT	TWILIGHT*
G1: (Marginal sea ice in high latitudes)	0.00	0.00	0.00
G2: (Sea ice in high latitudes)	0.10	1.00	0.50
G3: (Extratropical and ice-free ocean)	0.00	0.00	0.00
G4: (Tropical ocean)	0.10	0.10	0.10
G5: (Dry, homogenous and snow-free land)	0.90	0.90	0.90
G6: (Homogeneous, extratropical and snow-free land)	0.60	0.60	0.60
G7: (Homog., extratropical land with seasonal snow)	0.15	1.00	1.00
G8: (Homog., extratropical land with permanent snow)	0.30	2.00	1.00
G9: (Rough, dry and snow-free land)	0.30	2.00	1.00
G10: (Rough, extratropical and snow-free land)	0.70	0.70	0.70
G11: (Rough, extratropical land with seasonal snow)	0.20	1.00	0.30
G12: (Rough, extratropical land with permanent snow)	0.30	2.00	1.00
G13: (Homogeneous, tropical and non-dry land)	0.20	0.10	0.20
G14: (Rough, tropical and non-dry land)	0.25	0.20	0.25

Green text: Snow-free land surfaces

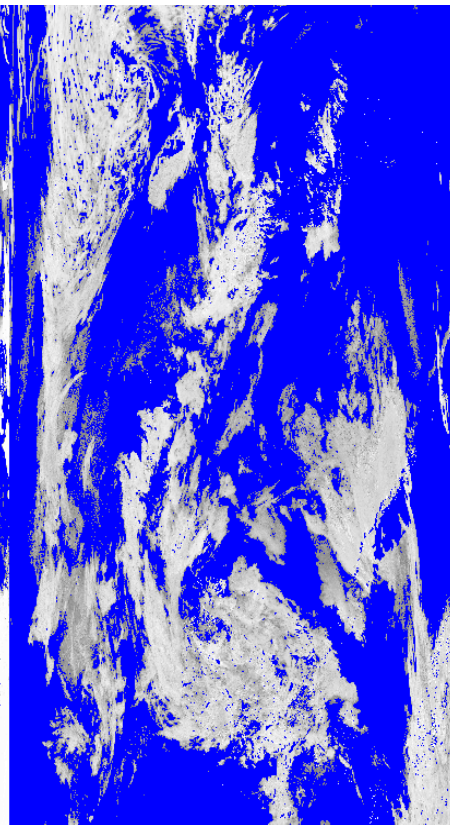
Blue text: Ice-free ocean surfaces

* Twilight value to be used in day portion of twilight zone (80-89 degrees)

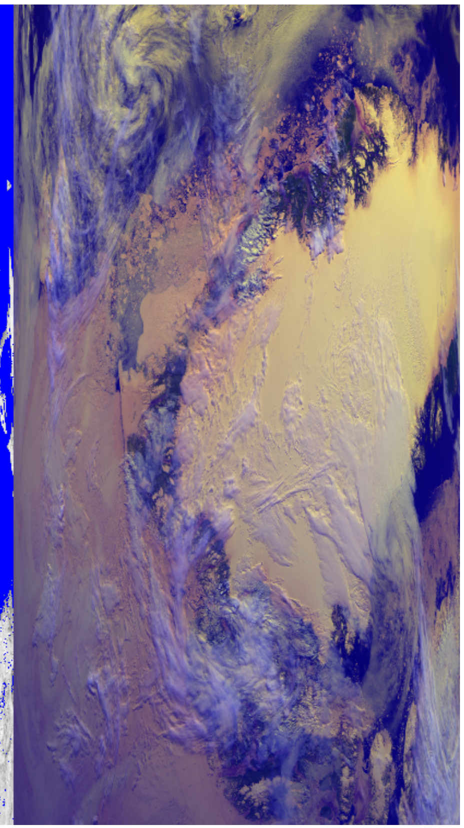
Demonstration of principles of adjusting probabilities over different surfaces:



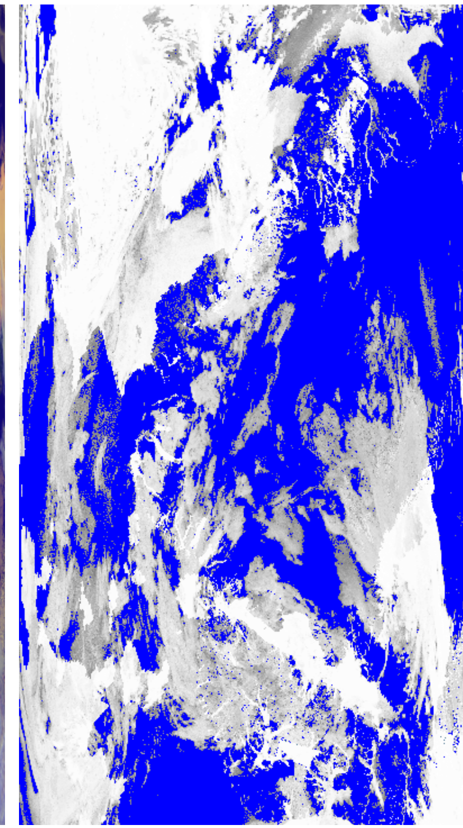
Probabilities trained with unfiltered CALIOP cloud mask



Probabilities trained with filtered CALIOP cloud mask at cloud optical thickness 5



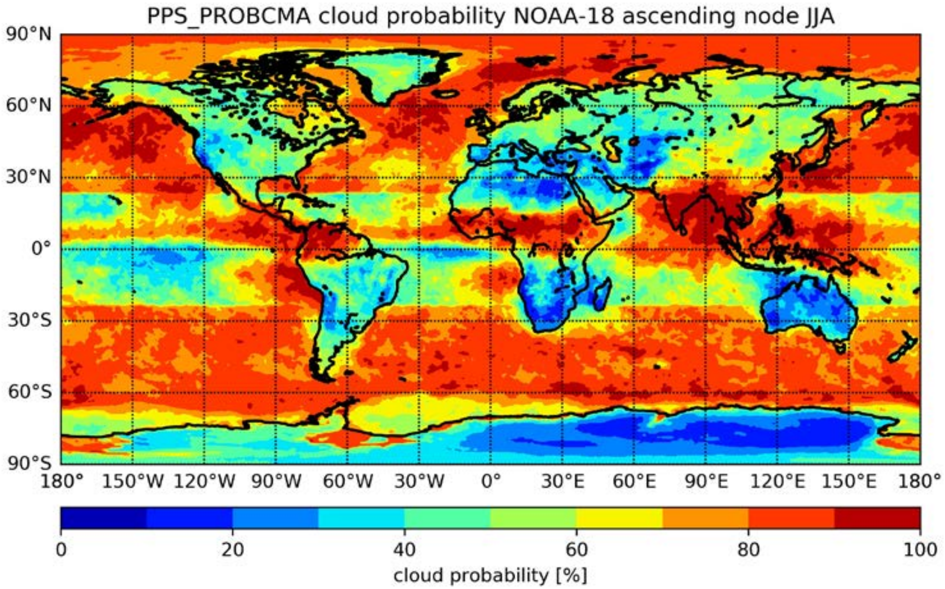
RGB (0.6, 0.9, 11 µm)



Final combined probabilities with filtered statistics used over cold land areas

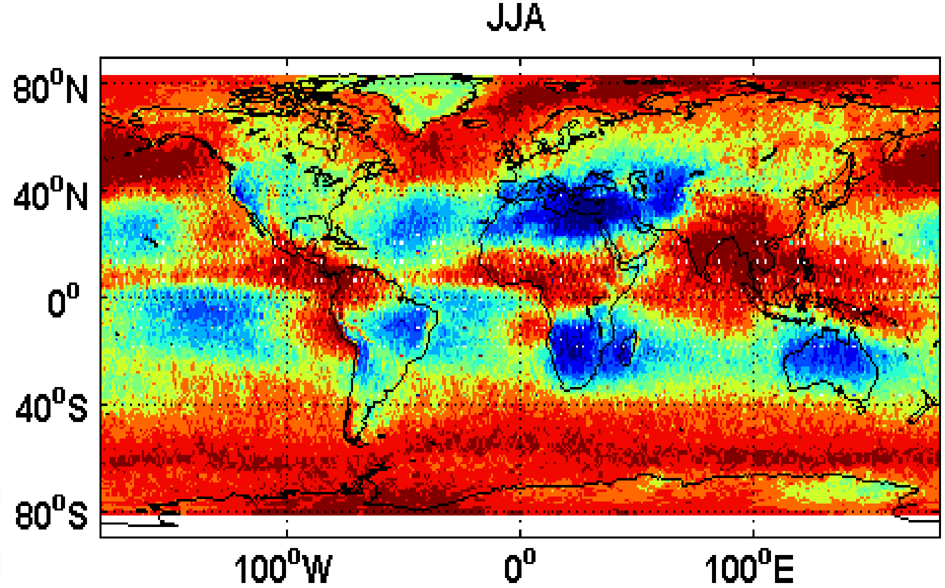
Example of Level 3 (type) results from CMAPROB cloud mask

Mean PPS 2018 cloudiness from all collocated NOAA-18 -CALIPSO scenes 2006-2015



Courtesy of Jan Musial

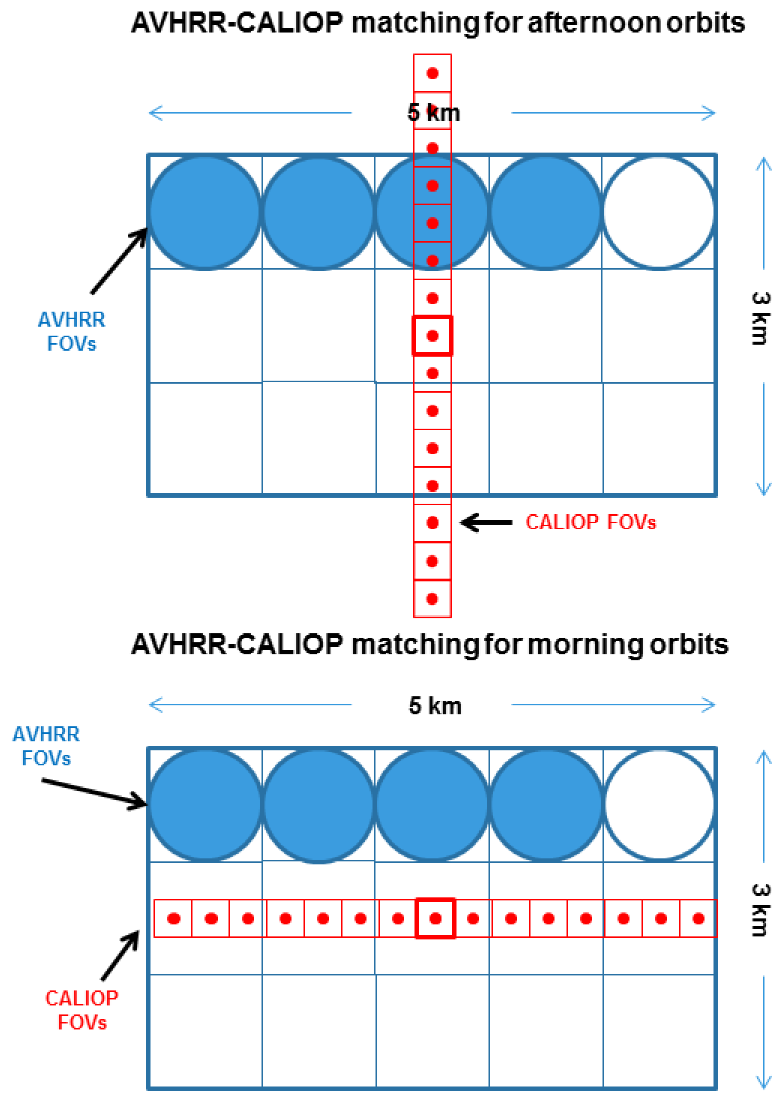
Mean cloudiness from <u>all</u> CALIPSO orbits 2006-2015 (CLAY 4.10)



Courtesy of Abhay Devasthale

Northern Hemisphere Summer

Remaining validation problems: Representativeness of CALIOP matchups



Only for clouds with scales larger than 5 km the matchup will be perfectly valid!

Consequences for validation:

- **Could be better to aggregate results on larger scales to avoid geometrical matchup problems**

- **But this complicates the use of associated cloud optical thickness information for cloud detection sensitivity studies**

- **A better concept could be to stay in finest (GAC) resolution and see residual errors as coming from geometrical matchup errors**

- **Both approaches used which makes inter-comparisons problematic. Can we agree on a common approach?**

Uncertainty of probabilistic cloud mask:

- **Probabilities cover only the likelihood that we have a cloud given a certain set of spectral features**

- **How do we estimate the uncertainty of the probabilistic cloud mask due to external factors (e.g. ancillary data, radiance noise, navigation accuracy, etc)?**

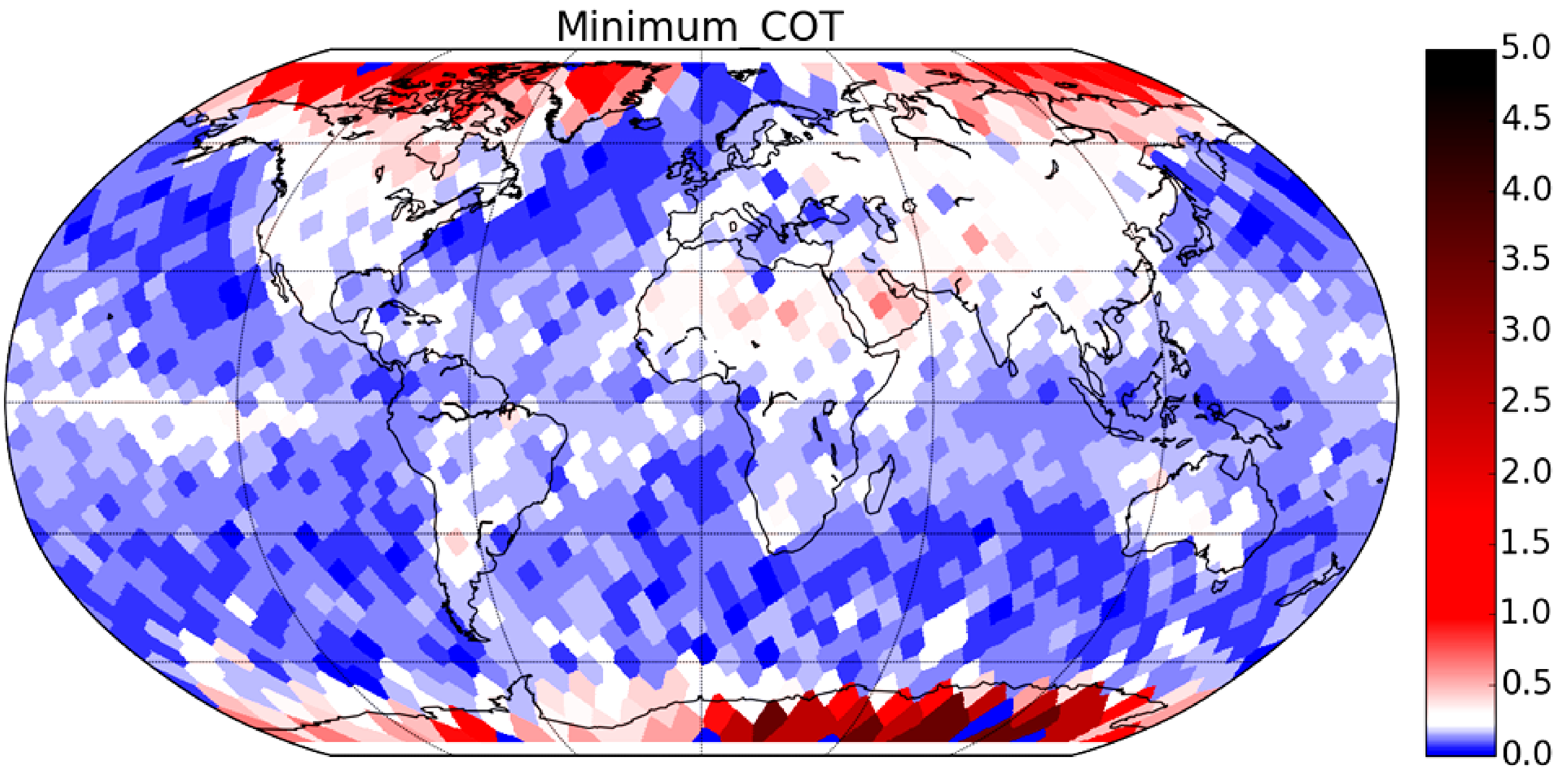
- **Monte Carlo simulations?**

New developments: Machine Learning approaches

- **Estimating cloud masks or cloud probabilities from artificial neural networks: Example ESA-CLOUD-CCI CC4CL cloud mask**

- **Direct estimation of Bayesian cloud probabilities: Example from the VEOR technique**
  (VEOR=Vectorized Earth Observation Retrieval)

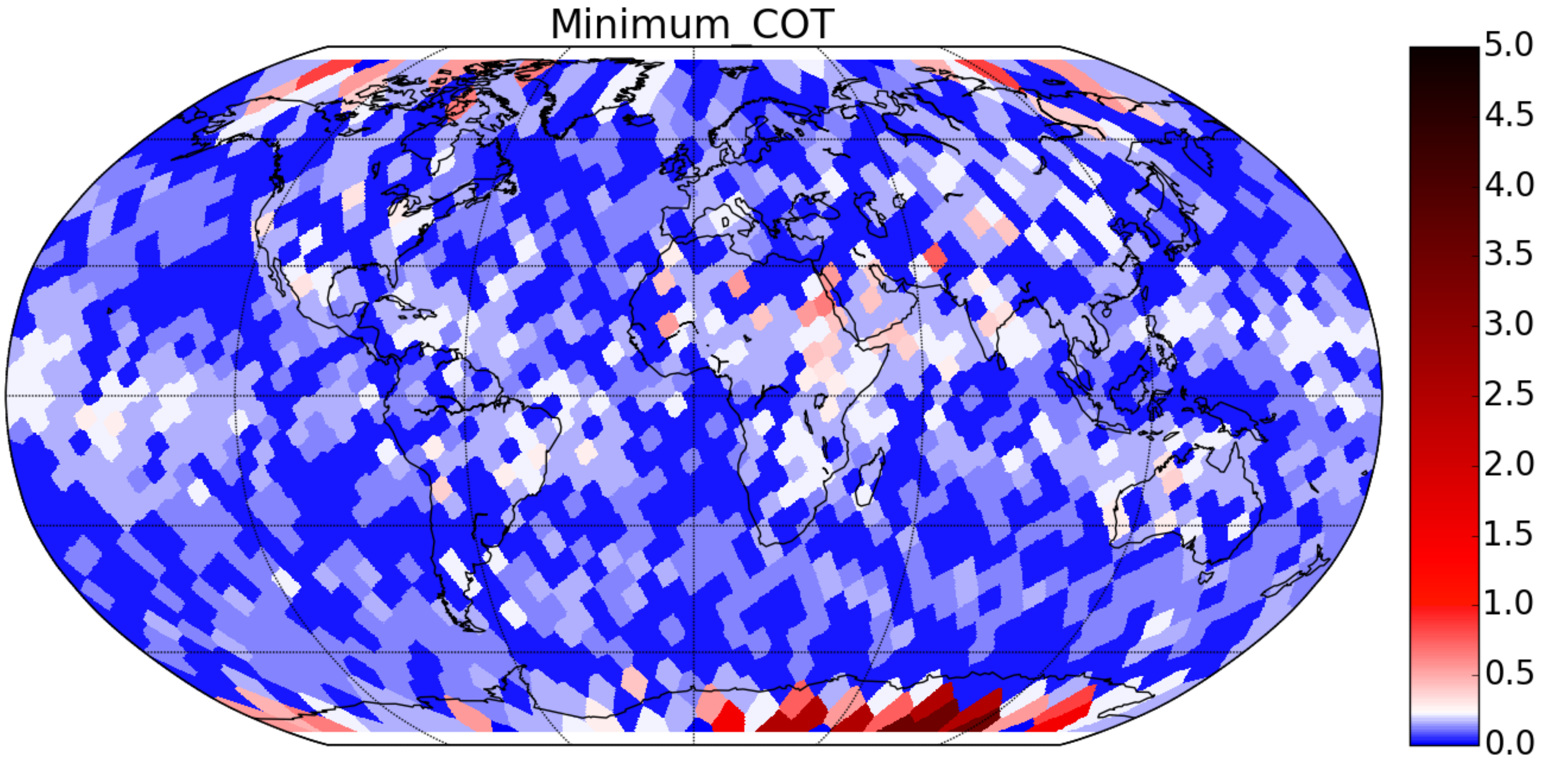
Cloud Detection Sensitivity for CLARA-A2



Global variation of **Cloud Detection Sensitivity** (= 50 % detection) for the CLARA-A2 cloud CDR expressed in minimum cloud optical thickness. Colour table shows values better than the global mean (0.225) in blue colors and values worse than the global mean in red colours.

(from Karlsson and Håkansson, AMT, 2018)

Results for CC4CL V3 (ESA-CLOUD-CCI)

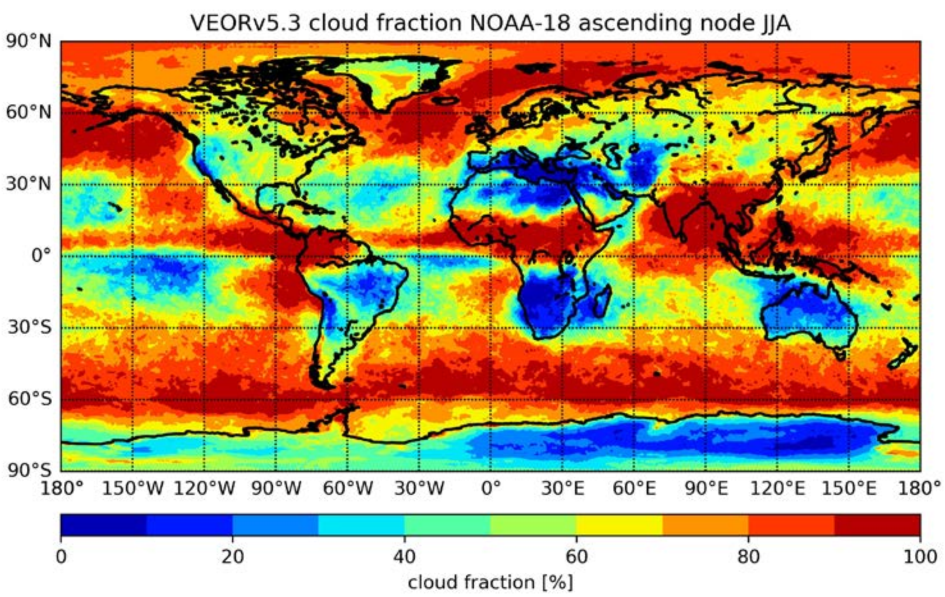


Cloud Detection Sensitivity: The minimum filtered CALIPSO COT value where 50 % of all cloud layers are detected (CC4CL global average COT = 0.21)

(from Karlsson and Devasthale, RS, 2018)

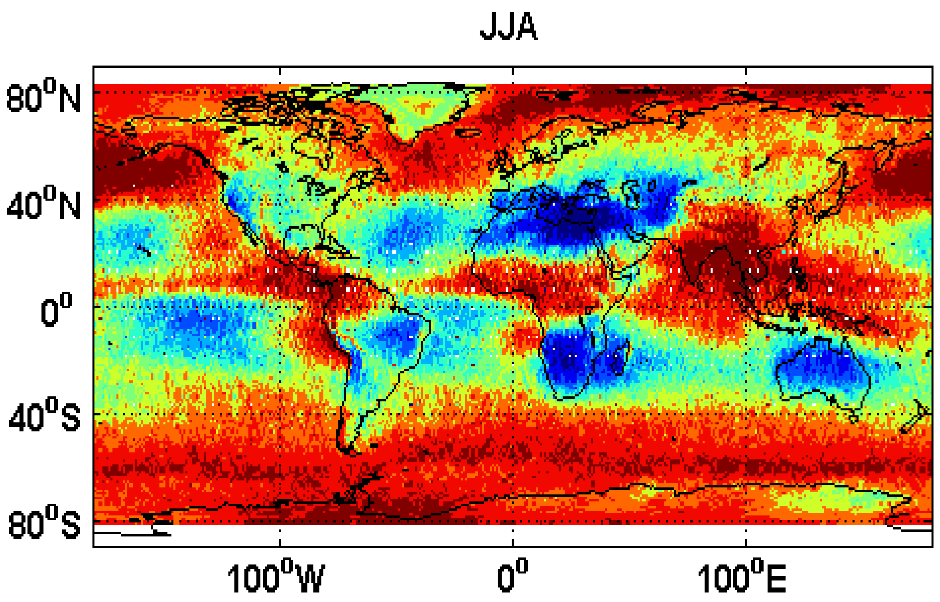
Jan Musial Visiting Scientist Study
– Example of results from VEOR probabilistic cloud mask

Mean VEOR cloudiness from all collocated NOAA-18 -CALIPSO scenes 2006-2015



Courtesy of Jan Musial

Mean cloudiness from <u>all</u> CALIPSO orbits 2006-2015 (CLAY 4.10)



Courtesy of Abhay Devasthale

Northern Hemisphere Summer

CONCLUSIONS

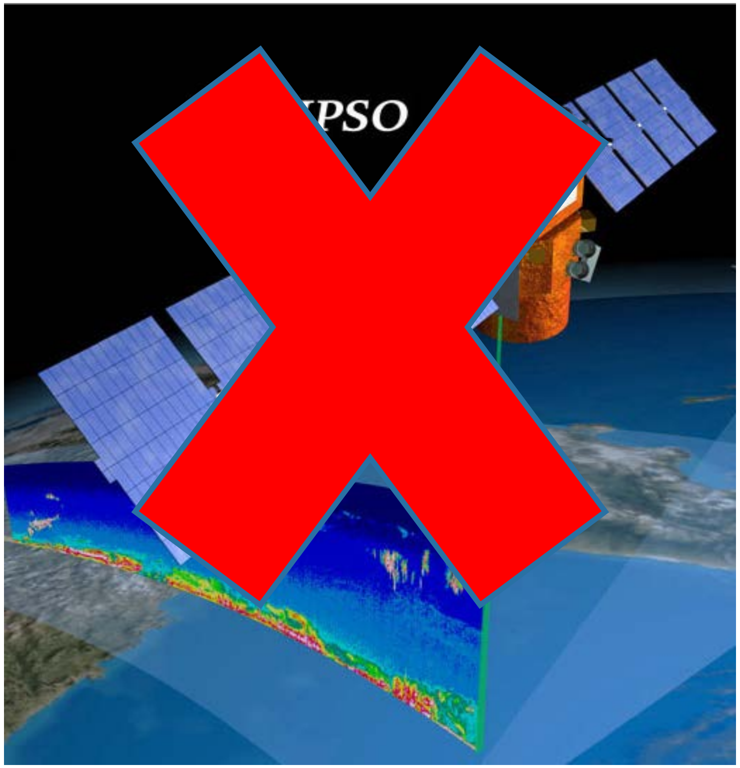
- Access to CALIPSO-CALIOP data has boosted development and validation of all available cloud screening methods

- New ways of assessing the quality of cloud masking methods have been introduced, e.g. the estimation of Cloud Detection Sensitivity. Can it be used in a broader context?

- Prospects for statistical methods and/or optimal retrievals (e.g. ANN-based) have increased drastically by the access to a stable “truth” covering almost all conditions.

- Machine-learning methods necessary for handling hyperspectral data from future sensors. BUT – this depends on successors of CALIPSO!

Access to cloud lidar information beyond CALIPSO-CALIOP ?????



- EarthCare (earliest 2022?)
- Beyond EarthCare?
- Stagnation of development of cloud monitoring methods possible
- A promising era of 3D-monitoring of clouds and cloud-radiative effects could come to an end
- If becoming a financial issue: Why not just repeat the (extremely successful) CALIPSO mission?