Lessons Learned from the Assimilation of Cloud-affected SEVIRI Radiance Observations at NCEP

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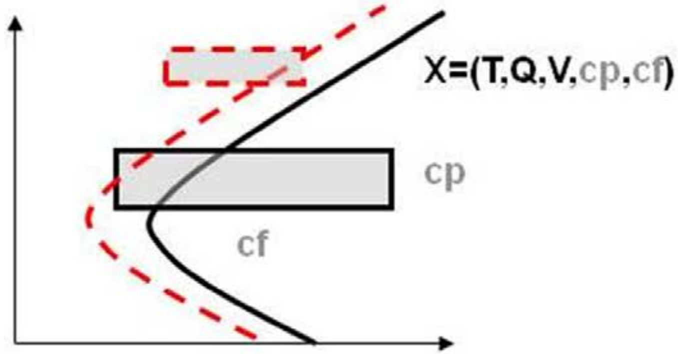
Background

- Large numbers of satellite radiances contain cloud and precipitation signal
- Most data assimilation system in current NWP screen the radiance data and reject cloud/rain contaminated observations, only assimilate the clear-sky radiance
- If cloudy radiances can be properly used, potentially will improve the forecasts of temperature, wind, moisture and cloud fields
- NCEP has been made using cloudy AMSU-A radiance data in operational
- Starting work with IR cloudy radiance data assimilation for IASI, CrIS, **SEVIRI**

Assimilate cloud-affected IR radiance

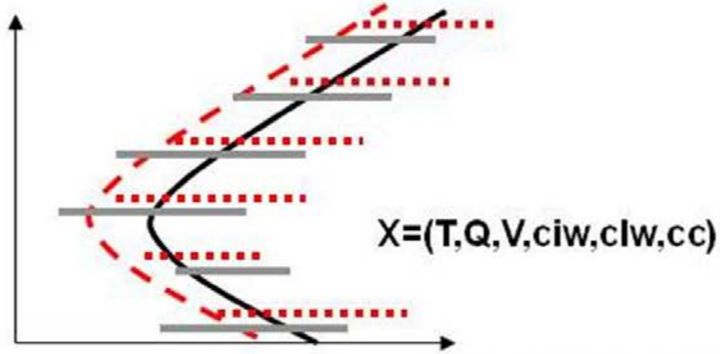
Simplified system:

- very simple cloud representation
- currently limited to overcast scenes
- no information on clouds taken from model
- no back interaction with model via physics



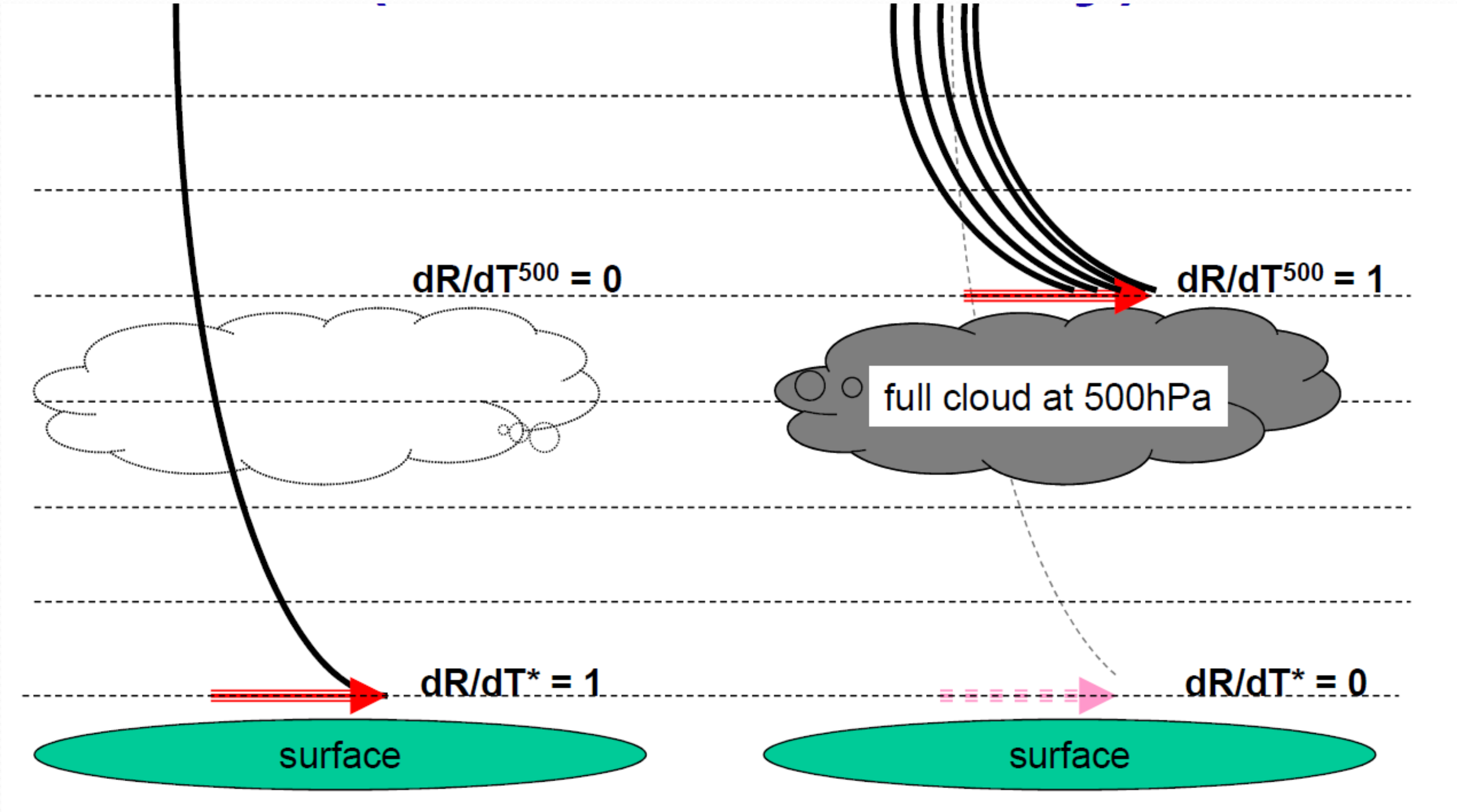
Advanced system:

- very complex cloud representation
- all cloud conditions treated
- information on clouds taken from model
- back interaction with model via physics



from: McNally,2012

Simplified cloud model (overcast data only)



from: McNally,2012

Methods

- For assimilating overcast radiance, observation-centered cloud top height is used as a control variable.
- In addition to modified $\partial T_B/\partial T(p)$, $\partial T_B/\partial q_v(p)$, etc., the minimization now incorporates the CTP Jacobian, $\partial T_B/\partial p_{cld}$.
- Under the grey-body assumption, the partially cloudy observation can then be considered for a single, fractional cloud as:

$$R_i = R_i^{clr}(1 - \mathrm{N}) + R_i^{overcast} N$$

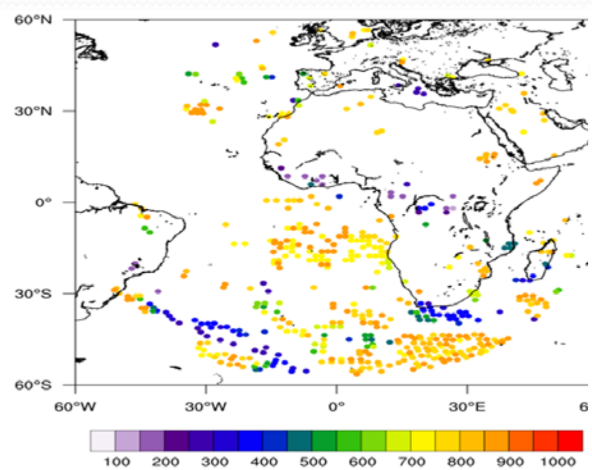
- The initial cloud top height and cloud fraction can be obtained from the GSI cloud detection algorithm, and will be adjusted during the minimization.

Benefit

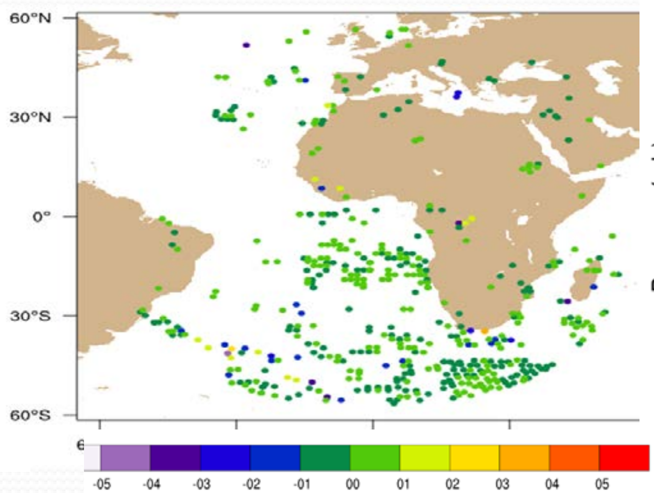
- Overcast conditions are least ambiguous in the radiance data
- Cloud control vector simplified to a single number (cloud top pressure), instead of complex hydrometer variables
- Do not need to consider cloud overlap situation
- Termination of Jacobians at cloud top provides new information, and measure temperature above clouds better than in clear sky
- No cross-talk between cloud and surface skin sink variables

Example of Analysis Increment

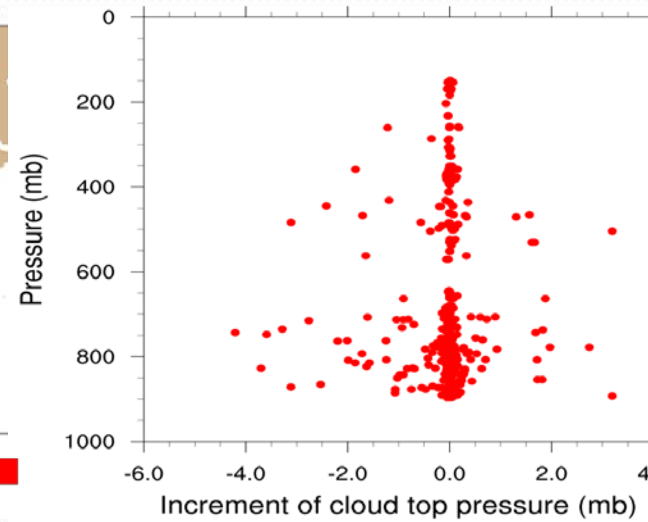
Cloud Top Pressure

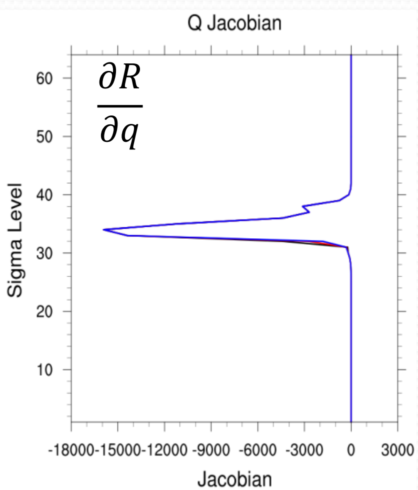


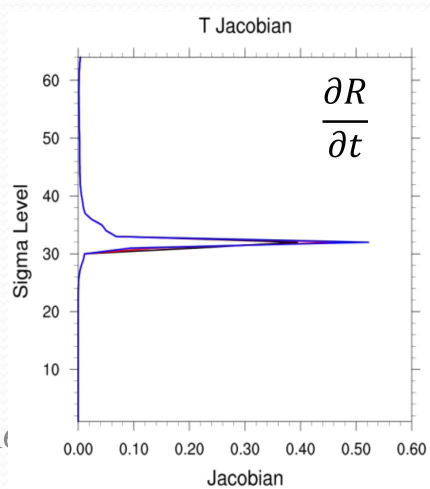
Cloud Top Pressure Increment



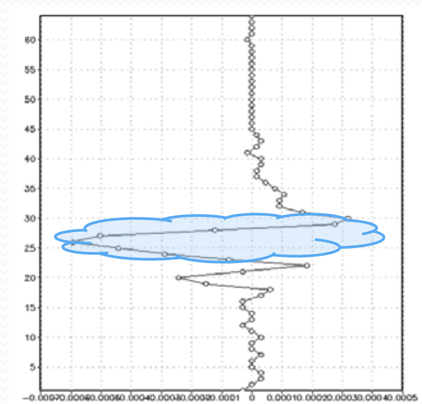
Cloud Top Pressure Increment







T increment



at the cloud top giving temperature increment above the diagnosed cloud top

IR cloud detection

- The simple RTM calculates a radiance at channel I *under the single-layer cloud assumption* as:

$$R_i = R_i^{clr}(1 - \mathrm{N}) + R_i^{overcast} N$$

- Using the minimum residual method (Eyre and Menzel, 1989) , minimize the cost function

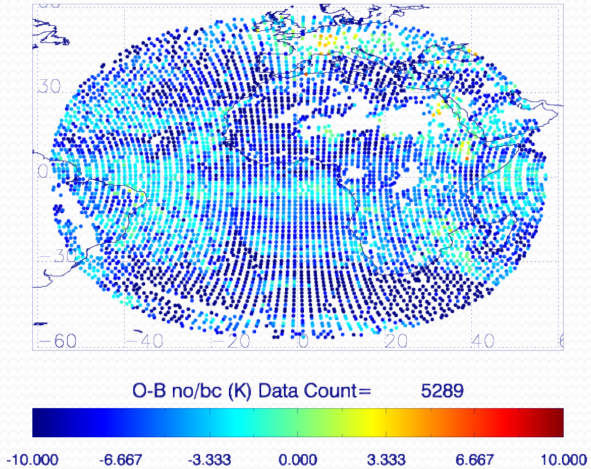
$$J = \sum_i (R_i^{obs} - R_i)^2$$

- By setting $\frac{dJ}{dN} = 0$, $\mathrm{N} = \frac{\sum_i \boxed{(R_i^{clr} - R_i^{obs})}(R_i^{clr} - R_i^{overcast})}{\sum_i \boxed{(R_i^{clr} - R_i^{obs})}}$

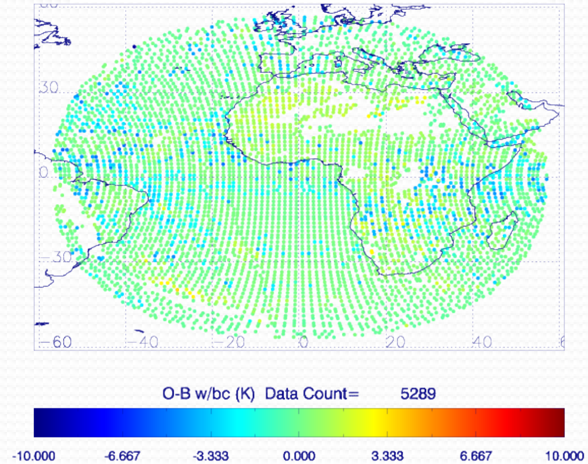
- Cloud top height was determined at a discrete model level where $R_i^{overcast}$ was calculate

O-B of 10.8 μm band BT.

Before Bias Correction

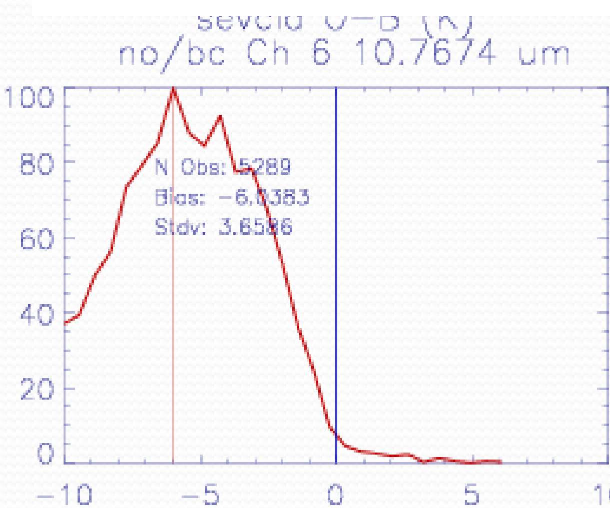


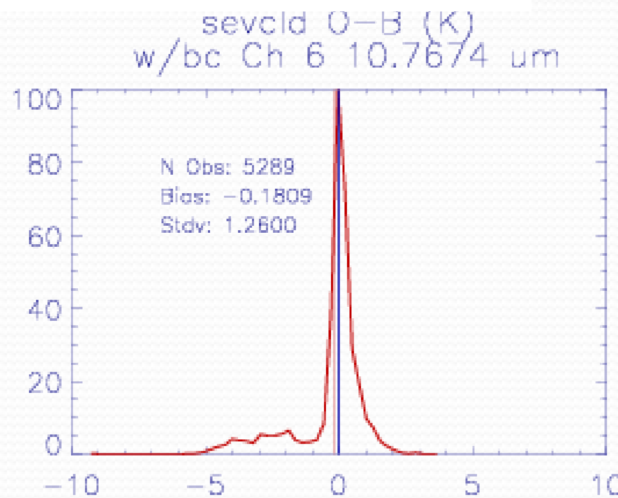
After Bias Correction



Model has warm bias/observation has cold bias

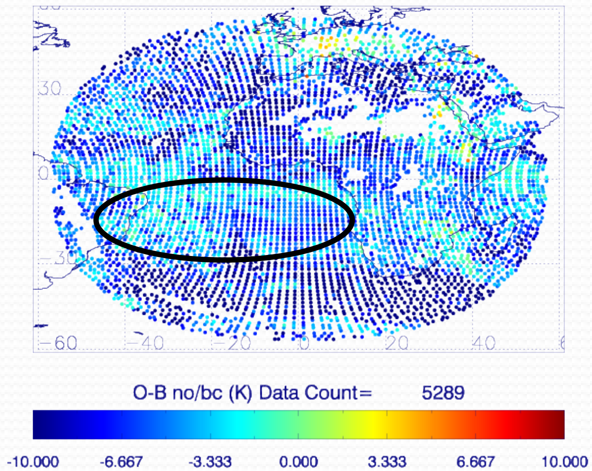
O-B Histogram



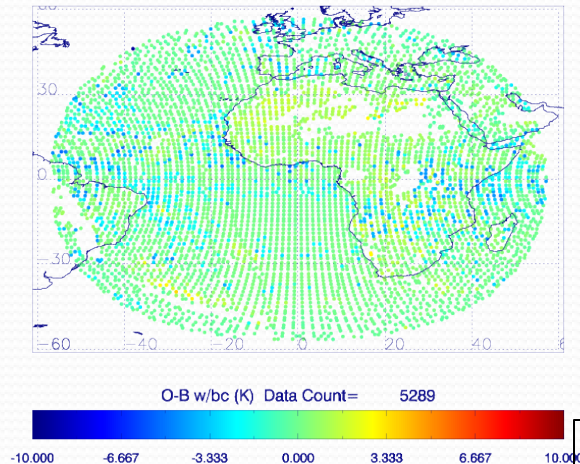


O-B of 10.8 μm band BT.

Before Bias Correction

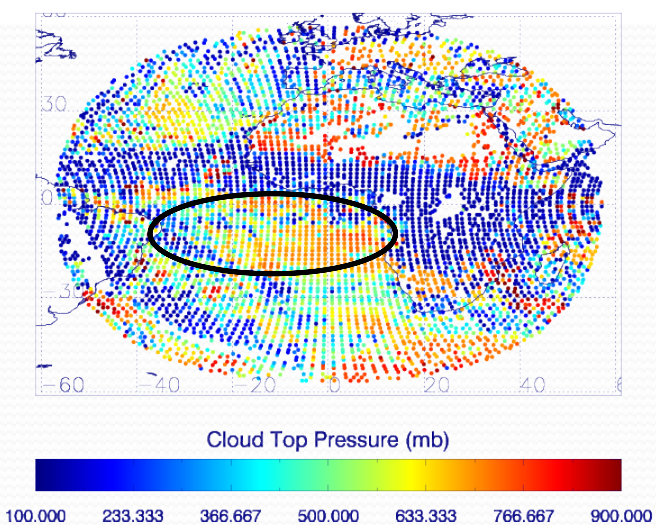


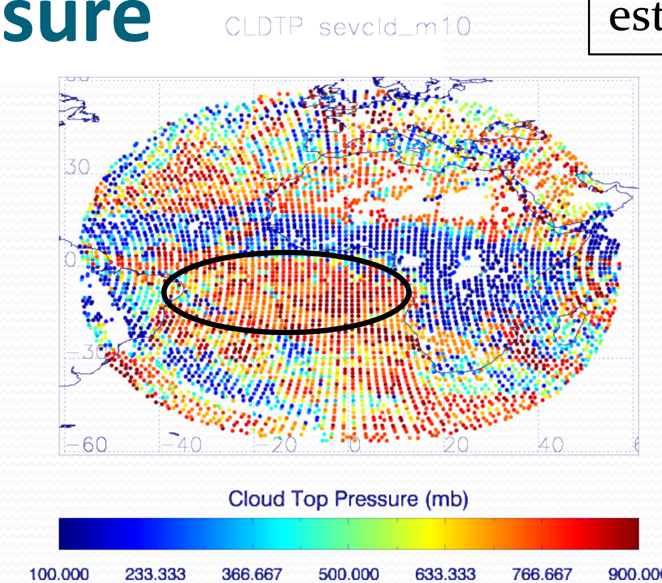
After Bias Correction



Model warm bias would lead to higher estimates of cloud top

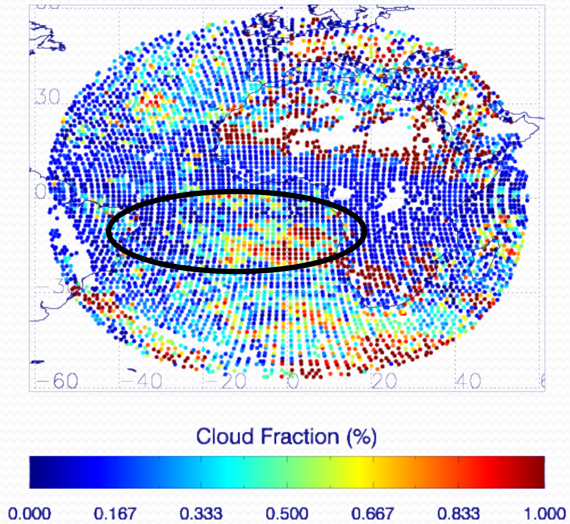
Cloud top pressure



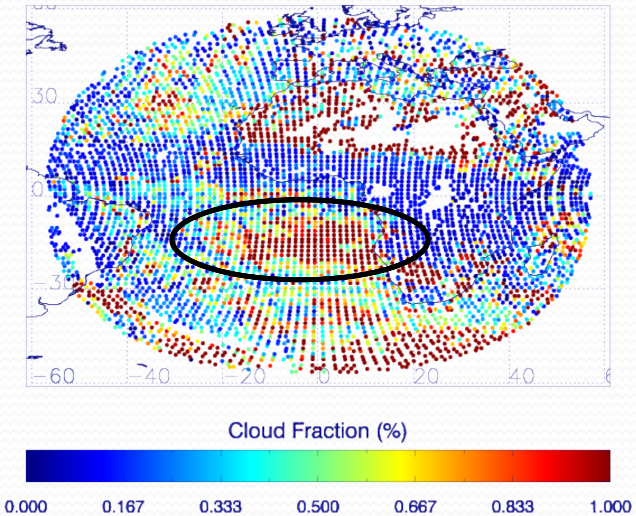


Cloud Fraction

Before Bias Correction



After Bias Correction



- Warm model bias would lead to smaller cloud fraction than really exist.
- This might cause the sharp temperature Jacobian at the wrong height and with wrong amplitude.
- So correct as many bias in models and measurements as possible before estimating the cloud top height and cloud fraction

Why exploring SEVIRI radiance?

- EUMESAT Meteosat Second Generation (MSG) Geostationary Satellite SEVIRI has the similar channels, resolutions as GOSE-R ABI
- So hopefully the lessons and experiences we learned from SEVIRI can be used for assimilating cloud-affected GOES-R ABI radiance into NCEP operational data assimilation system

SEVIRI *vs* GOES-R ABI

ABI chn #	SEVIRI chn #	Wave length (μm)	Main observation application
1		VIS0.47	Aerosol detection , visibility estimation
2	1	VIS0.6	Surface, clouds, wind fields
3	2	VIS0.8	Surface, clouds, wind fields
4		NIR1.4	Very thin cirrus clouds
5	3	NIR1.6	Surface, cloud phase
6		IR2.3	Aerosol, cloud particle size
7	4	IR3.9	Surface, clouds, wind fields
8	5	WV6.2	Water vapor, high level clouds, atmospheric instability
9		WV7.0	Water vapor, atmospheric instability
10	6	WV7.4	Water vapor, atmospheric instability
11	7	IR8.5	Surface, clouds, atmospheric instability
12	8	IR9.7	Ozone
13		IR10.35	Low-level moisture,cloud particle size
14	9	IR11.2	Surface, clouds, wind fields, atmospheric instability
15	10	IR12.3	Surface, clouds, atmospheric instability
16	11	IR13.3	Cirrus cloud height, atmospheric instability

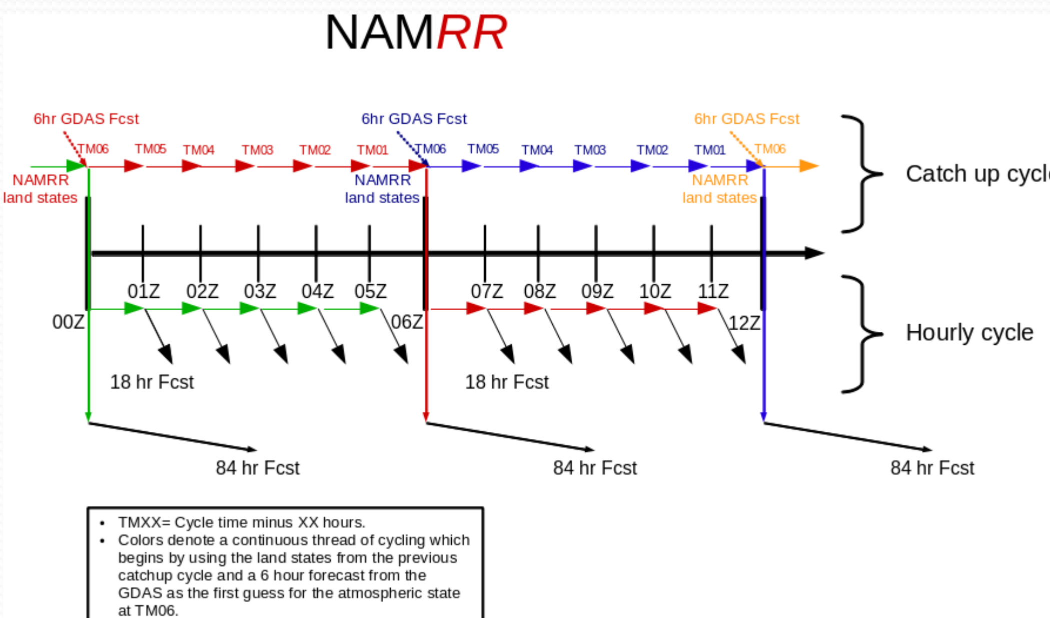
SEVIRI ~3 km footprint
GOES-R ~2 km footprint

2 water vapor channels are assimilated in GDAS

Forecast and data assimilation system

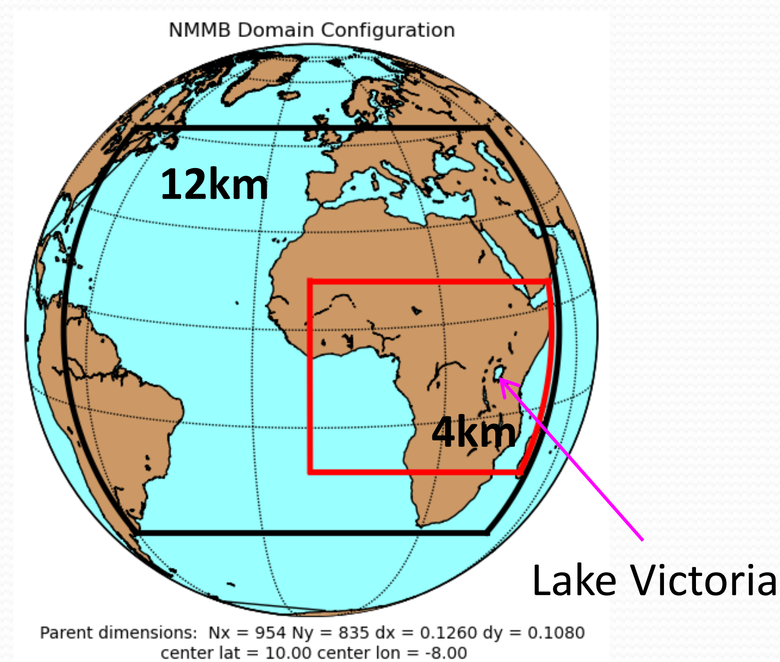
Hourly-Updated NAM Forecast System for Africa

- NAMRR: NAM Rapid Refresh
- Hourly updates
- Cycling 12 km parent and 4 km nest
- Hybrid ensemble-3DVar via Global Data Assimilation System's EnKF members



Park,

Africa Domain Config.



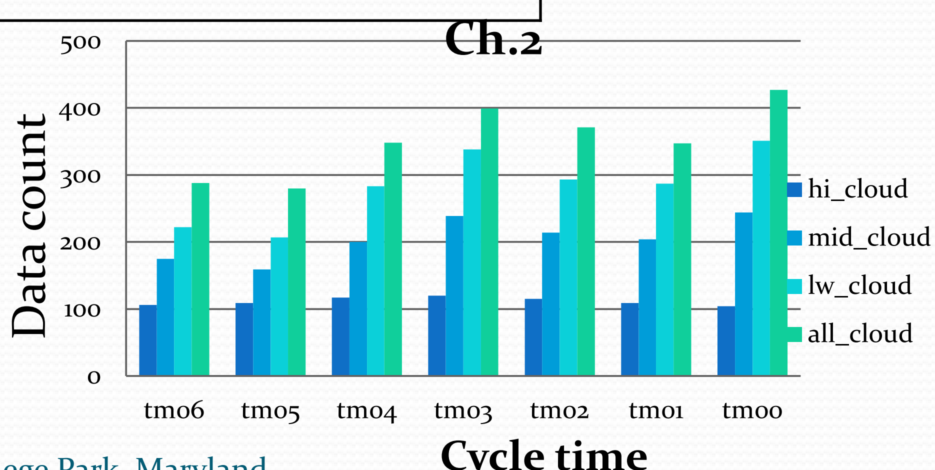
EUMETSAT SEVIRI ASR Product

Category	uses...
ASR-all	all pixels within a segment (16x16)
ASR-clear	all clear pixels within a segment(16x16)
ASR-cloudy	all cloudy pixels within a segment(16x16)
ASR-low	all low-level cloud pixels within a segment(16x16)
ASR-mid	all mid-level cloud pixels within a segment(16x16)
ASR-high	all high-level cloud pixels within a segment(16x16)

For verification

For assimilation

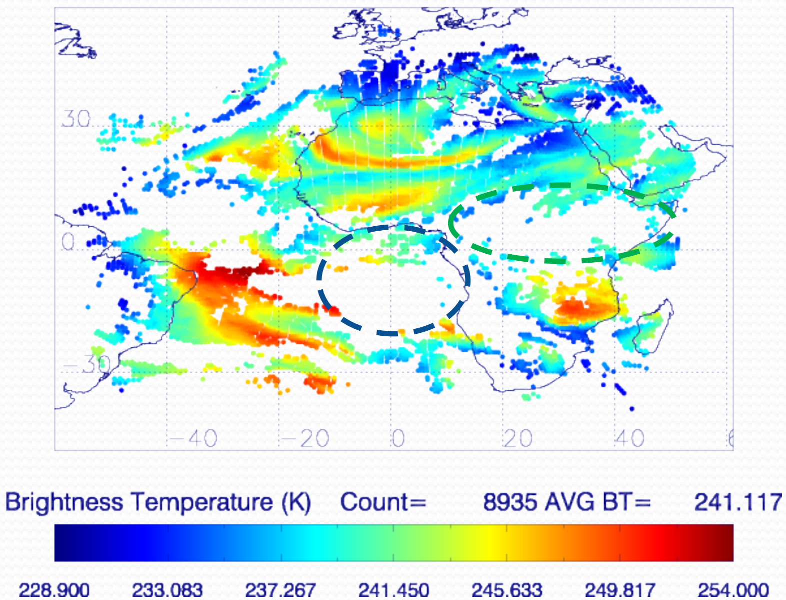
How much the cloudy data could be assimilated in each cycle with different cloud categories? Example→



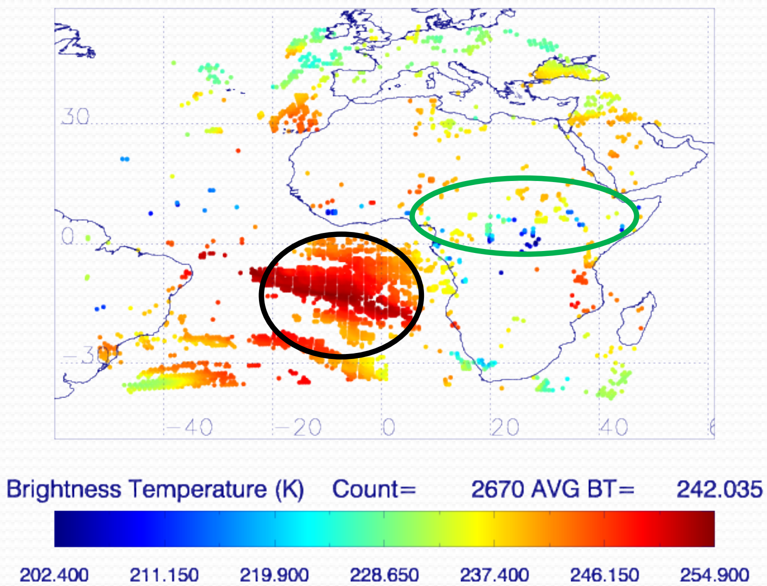
Assimilated SEVIRI Brightness Temperatures

Water Vapor Band (6.2 μm)

Clear-sky BT

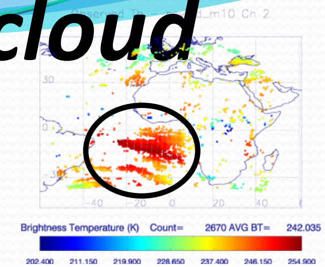


Overcast cloudy BT

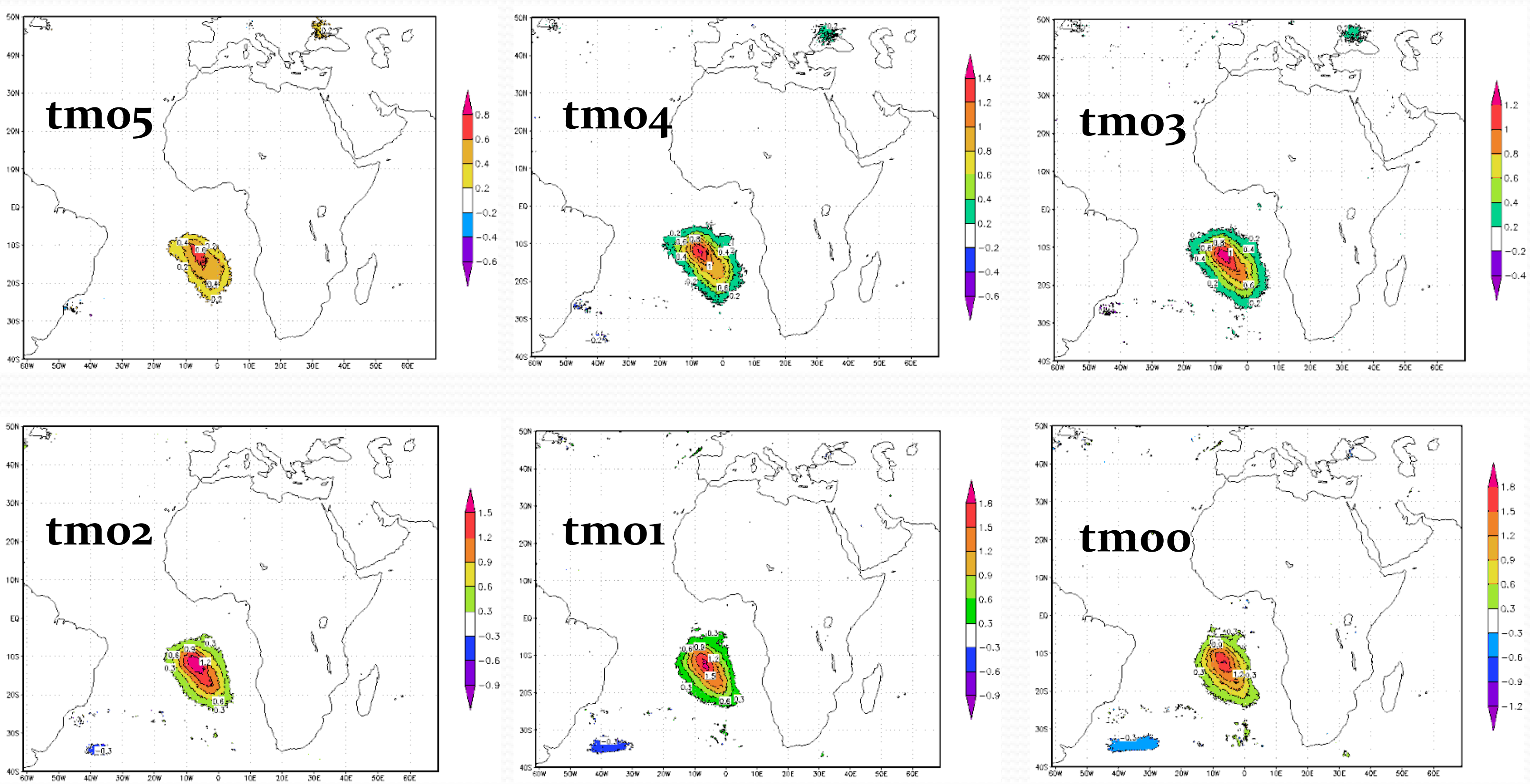


Cloudy observations add much more data over Atlantic Ocean
A few more data assimilated in mid-Africa

Analysis difference w/o overcast cloud

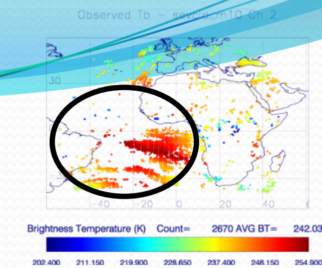


700mb Temperature Difference (m/s)

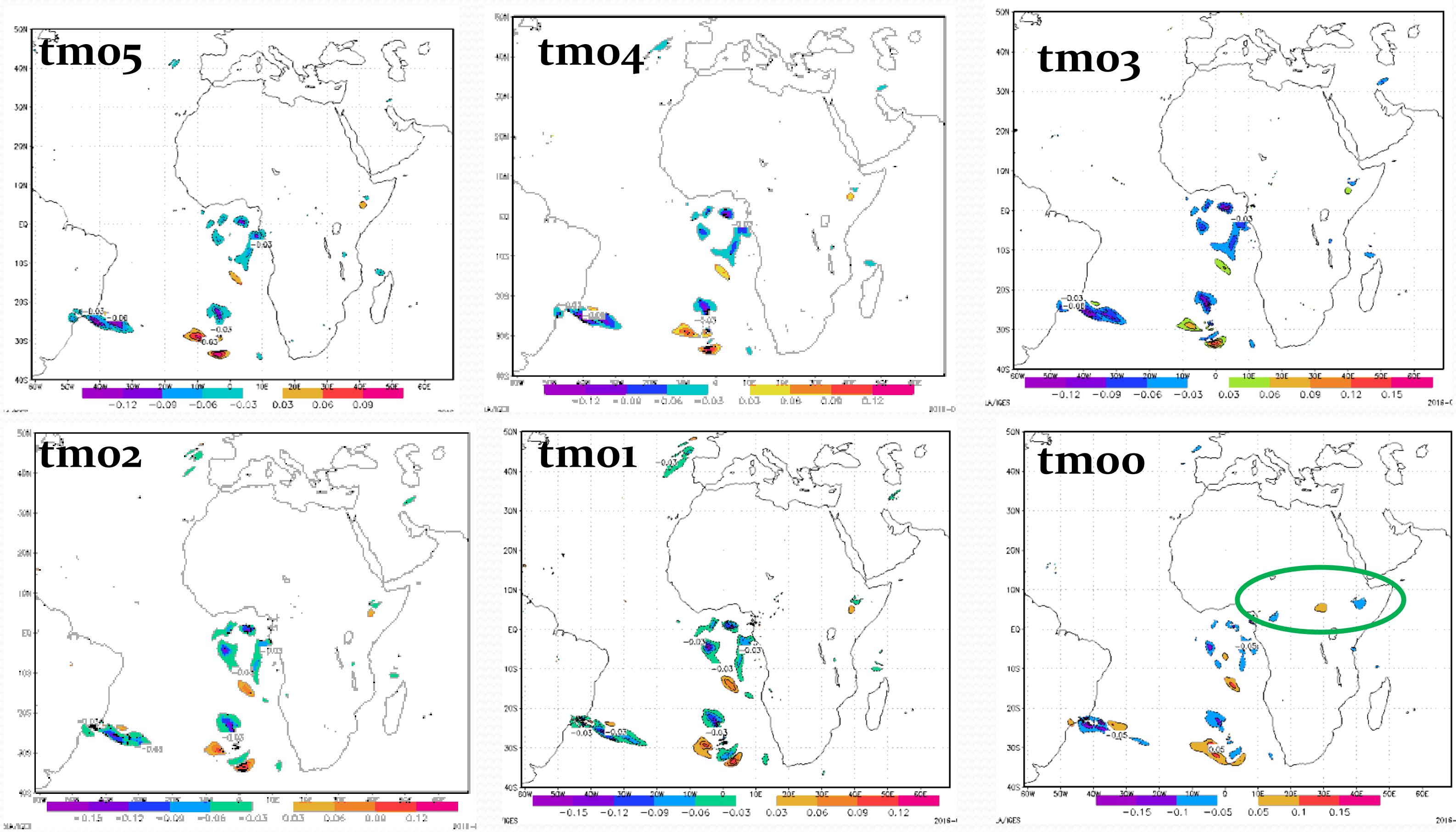


Temperature difference increased with the catch-up time

Analysis difference



300mb Specific Humidity Difference (g/kg)



Humidity difference for mid-Africa was observed at the last cycle.

Model Forecast Validation

- Assess NAMRR forecast for accuracy using SEVIRI infrared brightness temperatures computed from model fields using CRTM

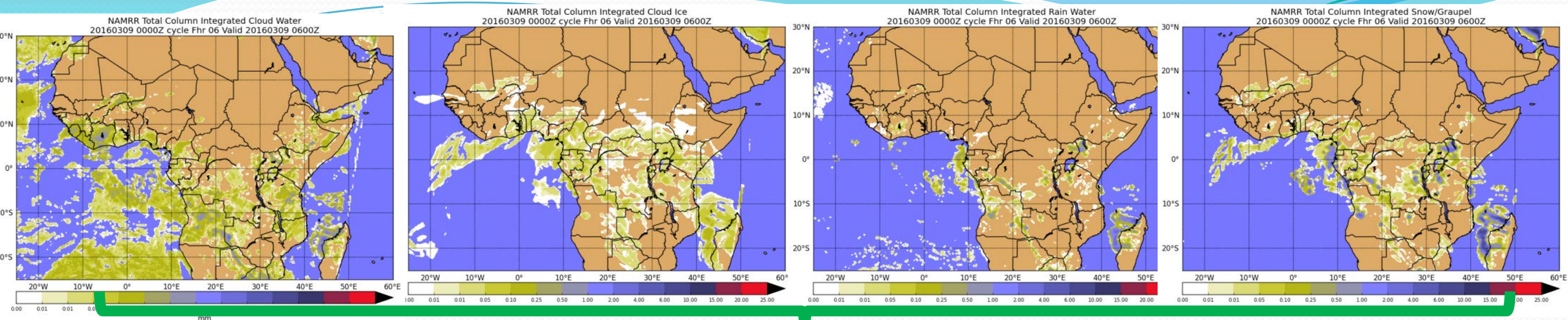
- This allow a direct comparison of forecasts with satellite data, especially for the data sparse area

- Primary focus is to assess the accuracy of cloud and moisture fields

- Using EUMETSAT SEVIRI All-Sky-Radiance (ASR) product from the 6.2 and 7.3 μm (water vapor sensitive) and 10.8 μm window channel (clouds and surface temperatures) and 13.4 μm (cirrus cloud)

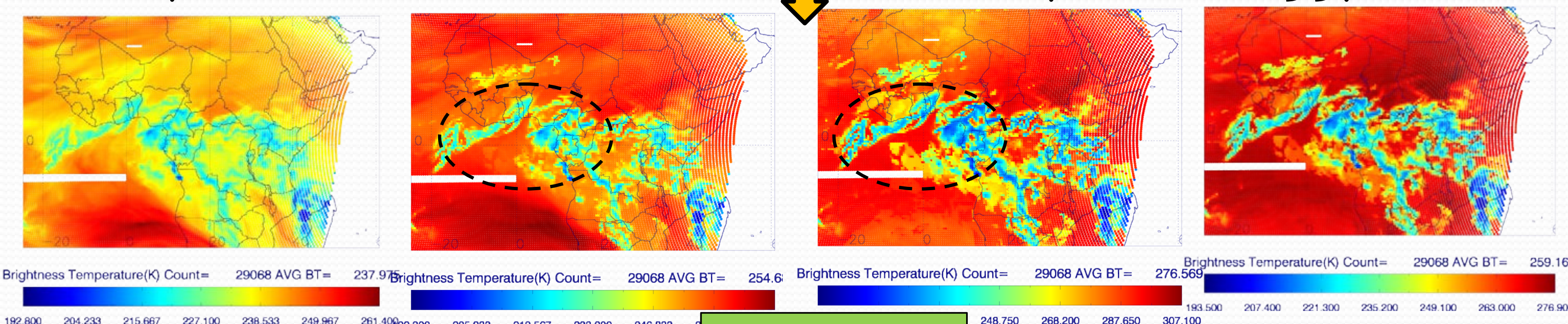
- In addition of the model forecast temperature and specific humidity profiles, cloud liquid water, cloud ice water, rain water and snow/graupel profiles are used by CRTM to compute the brightness temperature hourly

Cloud Water | Cloud Ice | Rain Water | Snow/Graupel

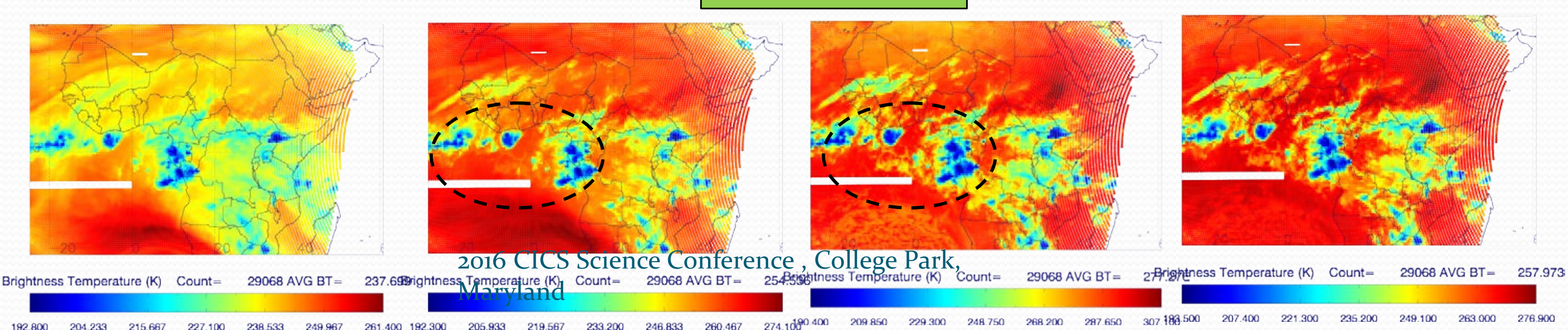


CRTM

6.2 μm BT | 7.3 μm BT | 10.8 μm BT | 13.3 μm BT

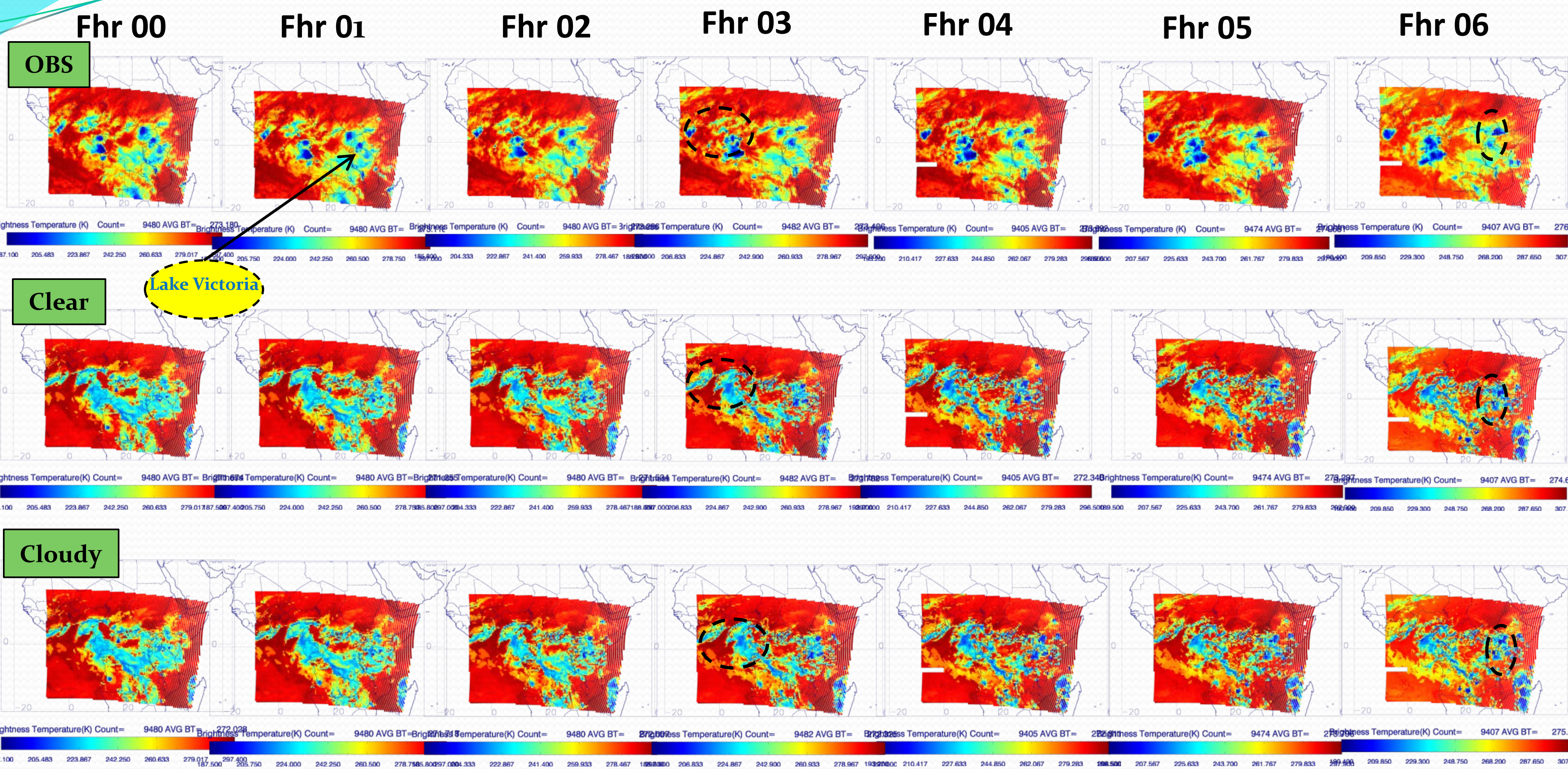


SEVIRI OBS



4km Model **hourly** forecast brightness temperature for window channel

20160309 00z cycle



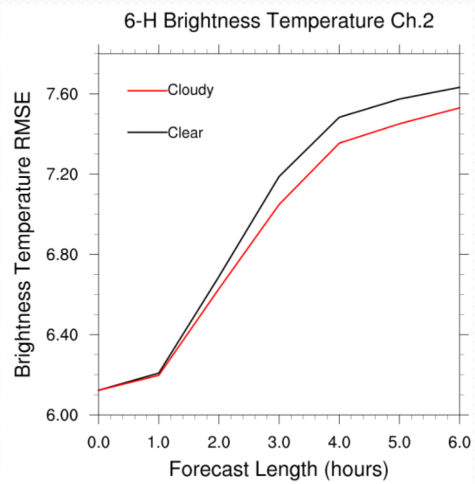
The location of cloud from 4km model forecast is consistent with observations for both clear and cloudy experiments. But model forecast for some convective clouds is very weak, except for Lake Victoria storm. There is no big difference Between 'clear' and 'cloudy'.

Model Forecast RMSE

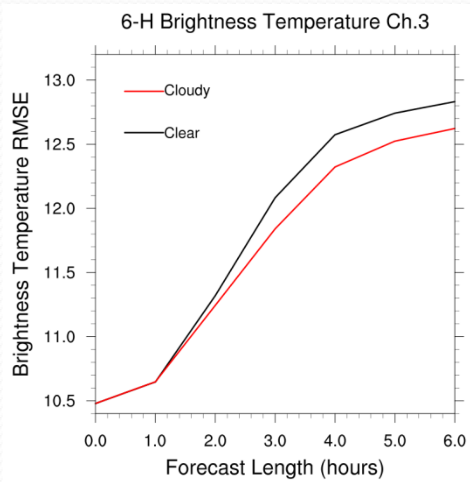
$$\text{RMSE}=\sqrt{\frac{1}{N}\sum_{i=1}^{n}(F_i - O_i)^2}$$

Calculated with the entire 4km nest 0-6 hs model forecast and SEVIRI all-sky radiance

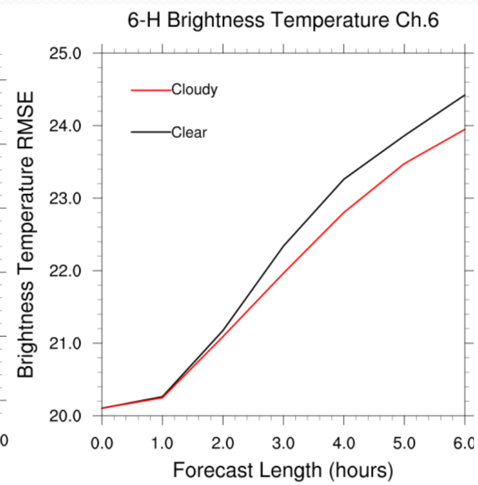
6.2 µm band



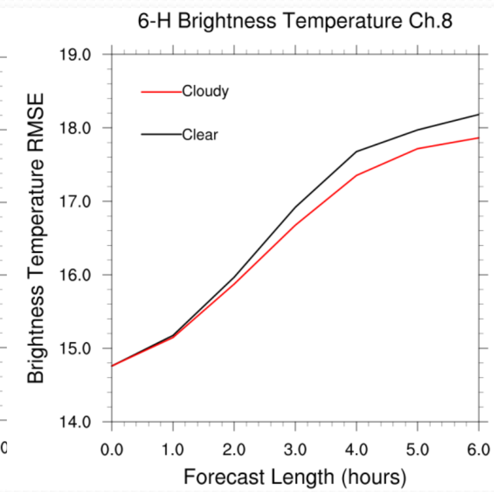
7.3 µm band



10.8 µm band



13.3 µm band



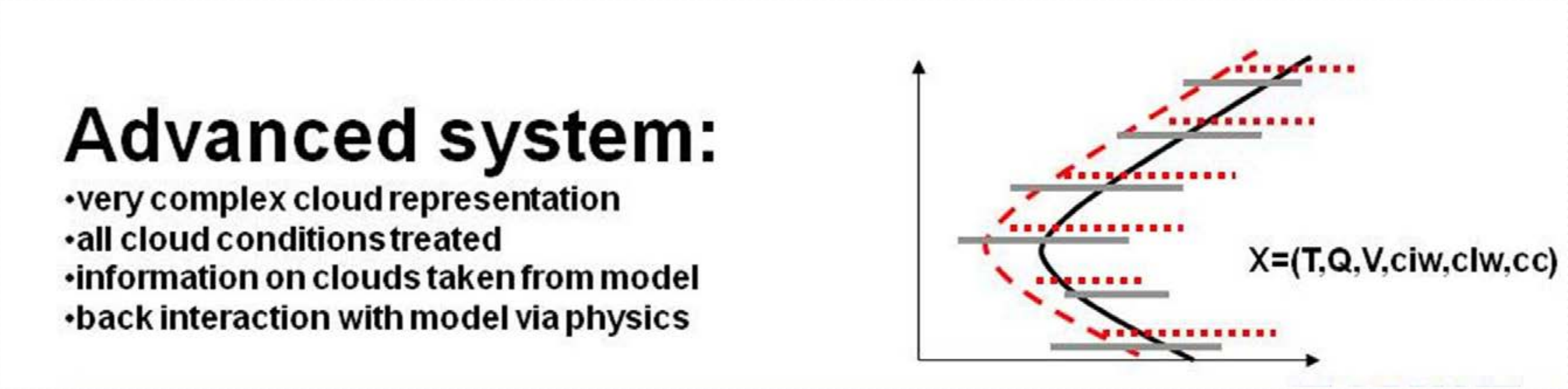
Experiment with overcast cloudy radiance has the smaller forecast RMSE for 1-6 hours.

Conclusions

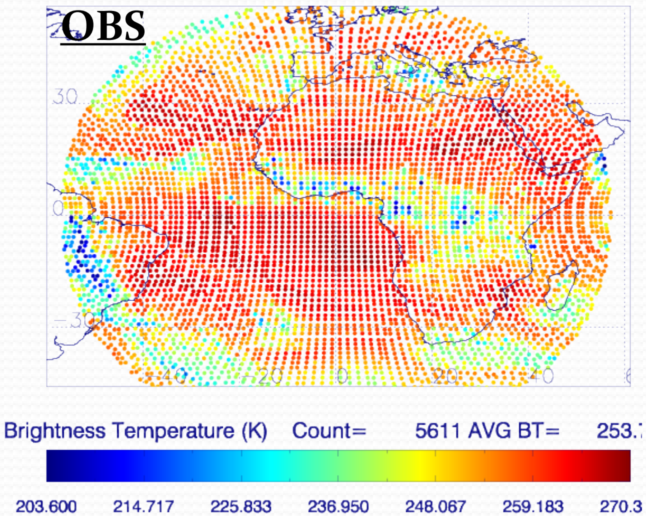
1. Through adjusting the cloud top height, overcast cloudy SEVIRI radiance are assimilated in both global and regional forecast, and has expected impact.
2. Cloud detection scheme is very important to assimilate IR overcast cloud radiance. The cloud top height is the crucial element to ensure the model simulated overcast radiance more accurate
3. Assimilation only overcast cloud IR radiance is not enough to improve the storm forecast for less data
4. NCEP NAMRR model forecast has the systematically weak convective clouds for Africa region with current physics scheme(Ferrier et al. (2002, 2011))

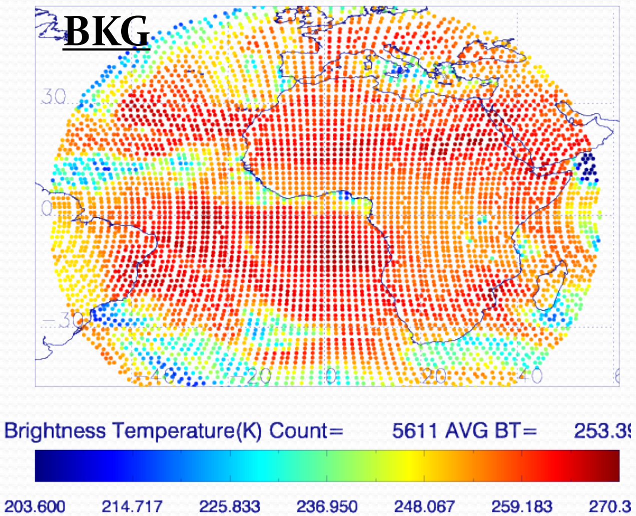
Future Works

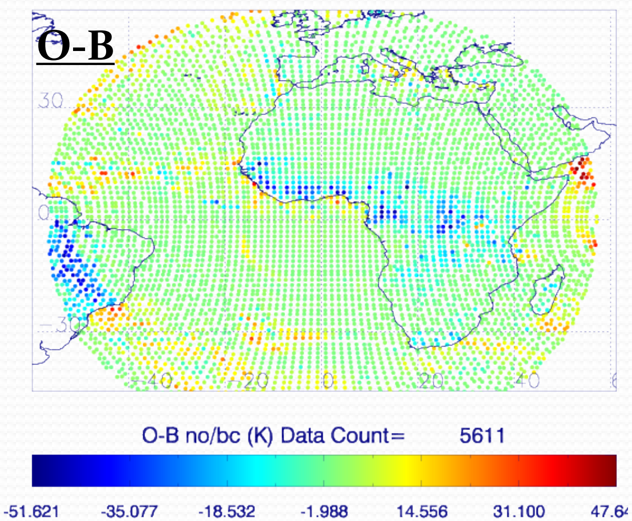
- Perform the direct assimilation of all-sky SEVIRI radiance with the hydrometeor variables (cloud ice, cloud water, rain water, snow/grauple…)

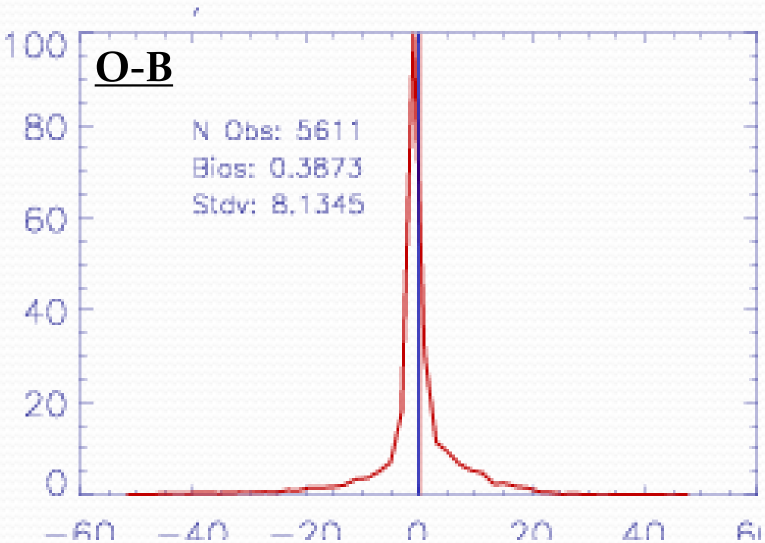


7.3 µm All-sky Brightness Temperature









THANKS!