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Validation of forecast cloud parameters from multispectral AIRS radiances

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Summary

1. Background
2. Methodology
3. Direct output model characteristics
4. CO_2 – slicing technique: description and improvements
5. Model validation results:
   - cloud top height and cloud amount distributions
   - cloud top height bias model vs retrieval
   - comparisons with CALIPSO cloud top height

6. Cloud parameters comparison with independent MODIS data sets
7. Monthly maps of cloud parameters in polar regions
8. Conclusion and prospective

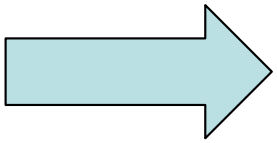
Background

- AIRS radiances assimilated operationally at EC (since June 2008)
  - 87 channels
  - radiances not sensitive to lower clouds are assimilated
- Therefore need to validate cloud height/amount determination for improved quality control
- By extension interest in validating trial fields of cloud parameters and more generally cloudy radiance spectra to infer model deficiencies
- Specific problems found in Arctic/Antarctic region linked to cloud parameter determination. Validation with independent data needed (MODIS, Calipso)

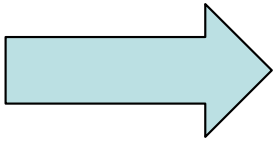
Basic idea

Model output combined with calculated cloudy radiances allows to validate cloud parameter retrieval methodology

- Effective cloud height and amount derived from CO_2 - slicing technique using observed AIRS radiances
- Same methodology used with calculated cloudy AIRS radiances from 6-h and 12-h forecasts



Eliminates ambiguity of definition of cloud parameters related to observed versus calculated.



Still a need to validate the quality of retrieved parameters

Methodology

INPUT:

Collected data: AIRS 281-channel set reduced to center pixel in 3X3 "golf ball" (in assimilation warmest, but this is not suitable for climatology of cloud parameters)

Forecast model: EC global model, 600 X 800 grid (~35 km), interpolated at the location of observation, 6 h forecast (valid interval 3-9h) and 12h forecast (valid interval 9-15h)

Radiative transfer model: modified RTTOV 8.7 version

Cloud optical properties: cloud overlap scheme [*Räisänen, 1998*], fixed liquid particle size (10 μm radius over land and 13 μm radius over ocean), ice particle size parameterization [*McFarquhar et al. 2003*]

Methodology

OUTPUT:

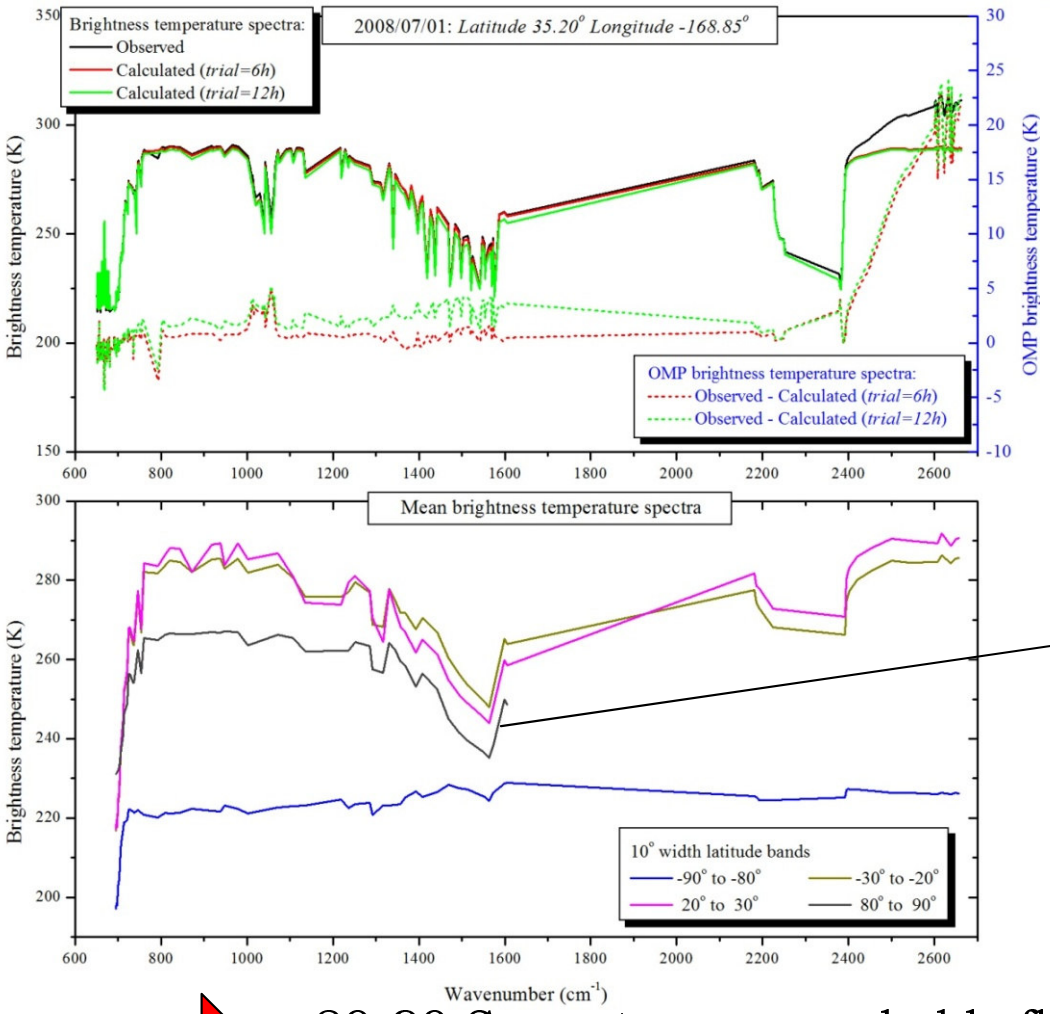
- All sky radiances/brightness temperatures from model output (one observed and two calculated using both forecasts
- Cloud top pressure (*CTP*)/height (*CTH*) and cloud amount (*Ne*) from EC CO_2-slicing method using observed and calculated radiances
- *CTP*/*CTH* and *Ne* using directly the model output

Additional cloud parameters:

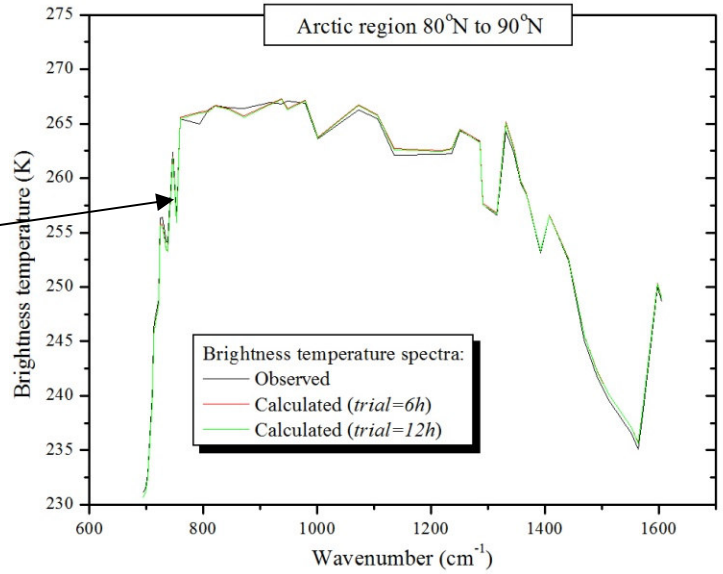
- *CTP*/*CTH* and *Ne* from AIRS Science team
- *CTP*/*CTH* and *Ne* from MODIS Science team
- *CTP*/*HT* and *Ne* from EC GOES processing

Latitude Longitude grid: 1˚ x 1˚ (mapping grid)

Observation vs Simulations: Brightness temperature comparison



Good agreement between observed and calculated radiances at pixel level as well as at monthly mean level



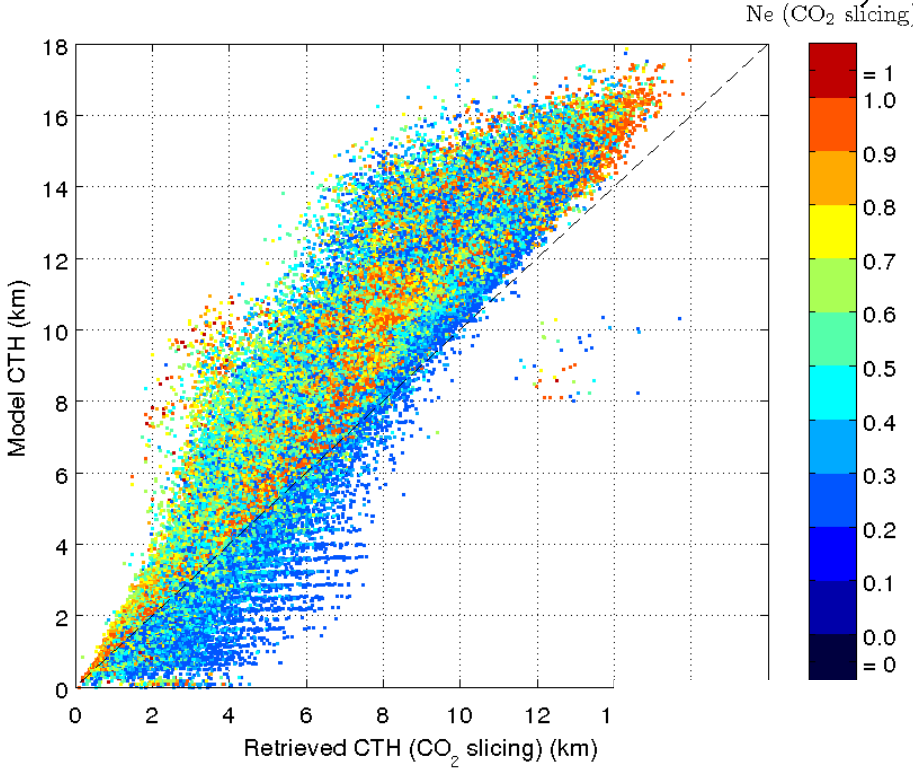
80-90 S spectrum remarkably flat: difficulty of sounding in polar night conditions

Direct output model

Cloud parameters derived from direct model output are sensitive to the threshold value τ_{cloud}

CTP/CTH = downward cloud transmittance (for 11 µm channel) from model top reaching $1 - \tau_{cloud}$

Amount = 1 – total cloud transmittance, effective cloud amounts < τ_{cloud} ignored



τ_{cloud} = 5 %

τ_{cloud} = 10 %

τ_{cloud} = 20 %

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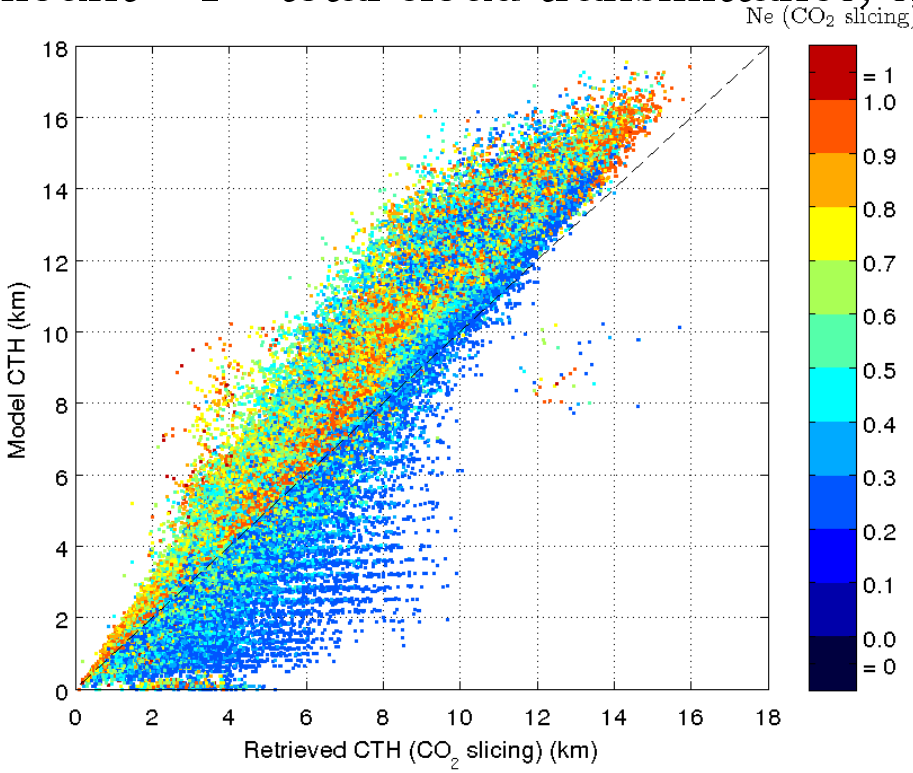

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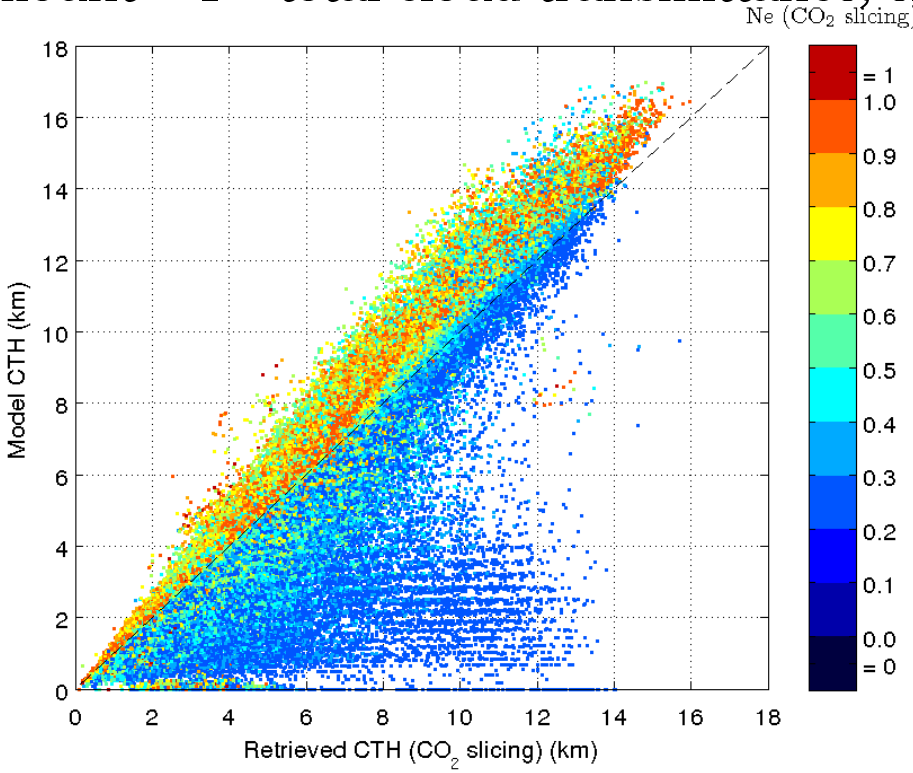


τ_{cloud} = 5 %

τ_{cloud} = 10 %

τ_{cloud} = 20 %

Increasing the threshold will decrease the bias, but also the detection of multilayer clouds

A compromise value of 10 % was chosen for future tests

CO_2-slicing technique: minimum residual method

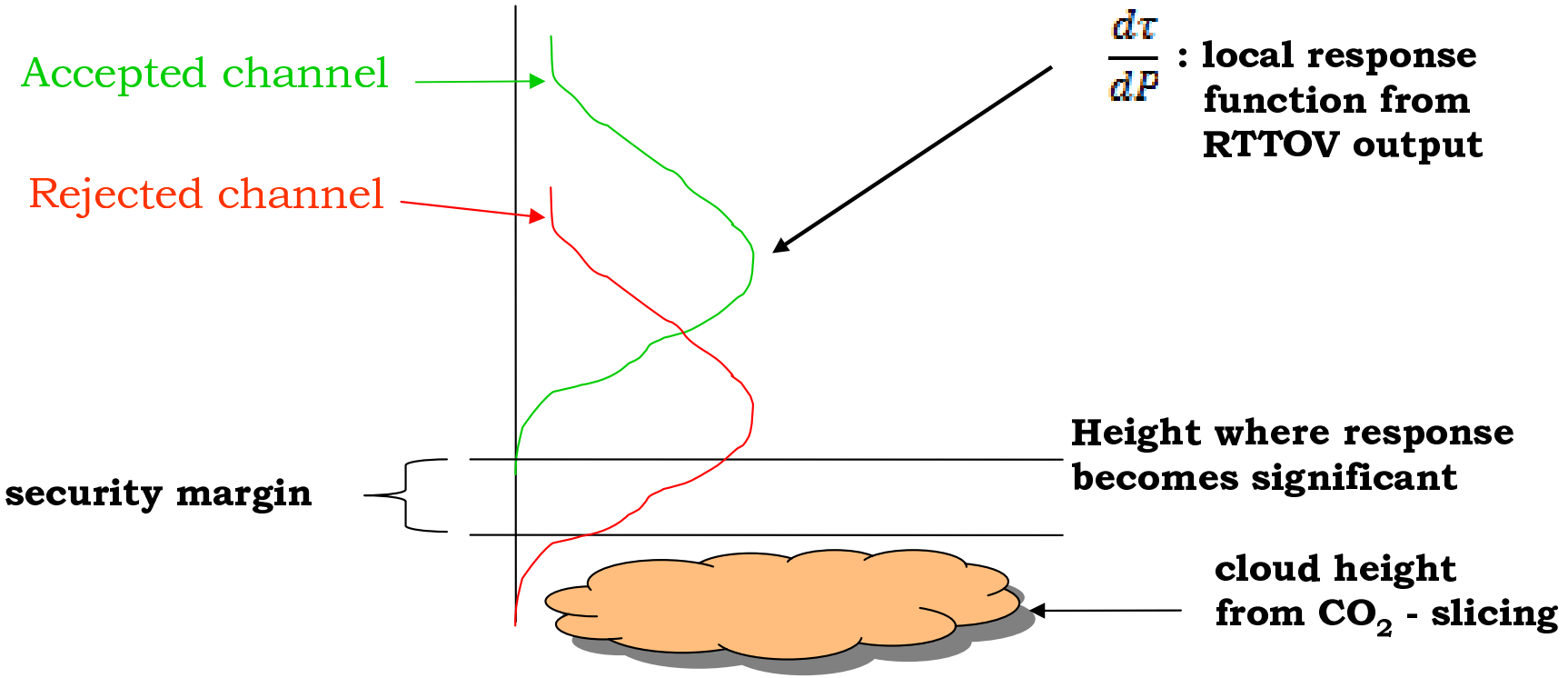
- Dates back to 80s (Menzell et al 1983, Eyre and Menzell, 1989)
- Still the only methods to retrieve equivalent cloud height and amount from single IR FOVs
- Based on radiance ratio of 2 channels, assuming same cloud emissivity, solves for effective height and amount

Issues:

- Channel pair selection
- Assumption on emissivity ratio unity
- Identification of reliable results

CO_2-slicing technique: cloud height/amount

- CO_2 slicing: estimates of cloud height from as many coupled channels. Mean of valid estimates is used.
- Assimilation of cloud unaffected radiances with a security margin (50 hPa STD among valid estimates)



Revision of CO_2-slicing technique to get cloud height and amount

following this study

- 13 radiance pairs used, all in range 13.2-14.1 μm
- Median value of height retained with corresponding effective amount

before

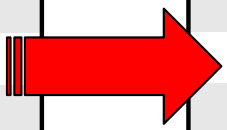
- Original implementation for AIRS in 2004 used 12 pairs with channel 528 (12.2 μm) used in all pairs. Mean retained.

elsewhere

- Several centers use a window channel like 787 (10.9 μm) as reference channel.

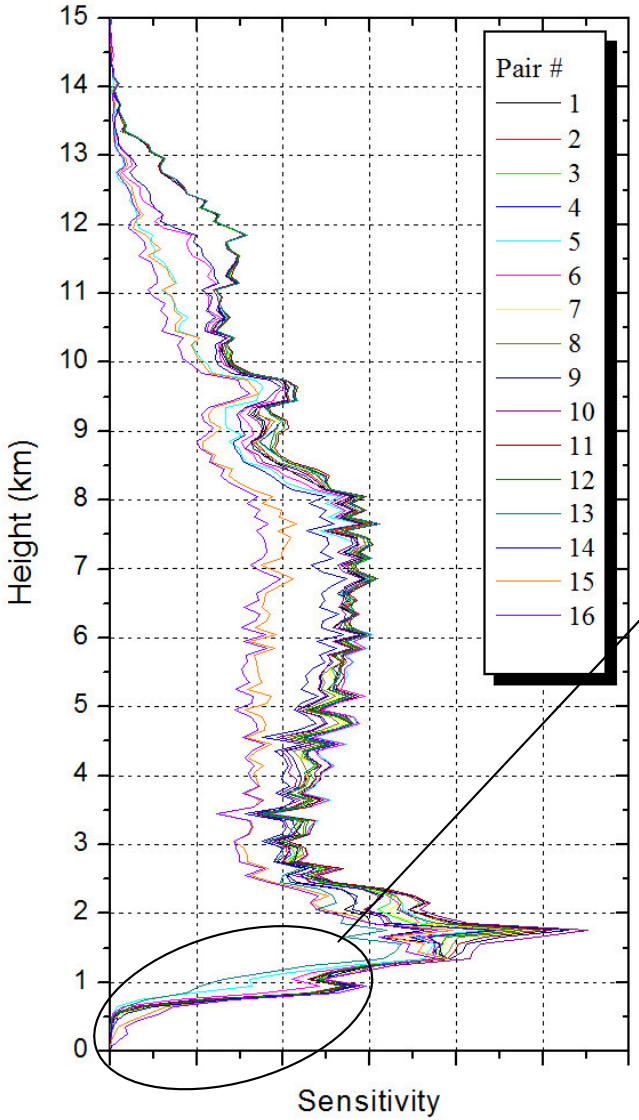
CO_2-slicing technique: channels configuration

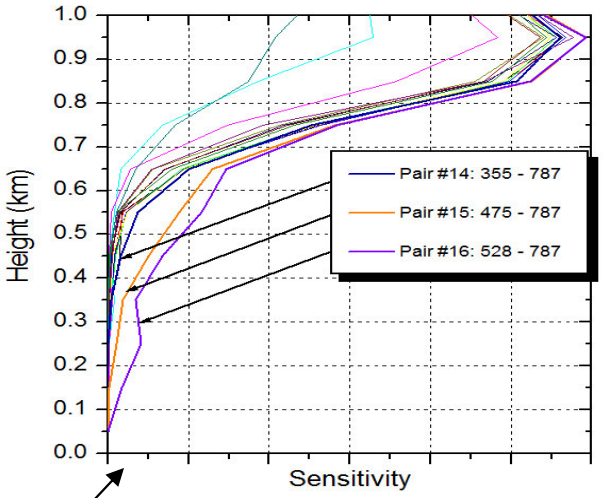
Initial configuration: 12 channels coupled with a reference channel	
Channel #	Wavenumber
204	707.770
221	712.661
232	715.862
252	721.758
262	724.742
272	727.752
299	735.298
305	737.152
310	738.704
355	752.970
362	755.237
475	801.001
Reference channel	
528	820.731



Tested configuration: 16 pairs of coupled channels				
	Channel		Reference channel	
Pair #	#	cm^{-1}	#	cm^{-1}
1	**204**	707.770	**252**	721.758
2	**221**	712.661	**262**	724.742
3	**232**	715.862	**272**	727.752
4	**252**	721.758	**299**	735.298
5	**262**	724.742	**305**	737.152
6	**272**	727.752	**310**	738.704
7	**299**	735.298	**355**	752.970
8	**305**	737.152	**362**	755.237
9	**310**	738.704	**375**	759.485
10	**355**	752.970	**375**	759.485
11	**362**	755.237	**262**	724.742
12	**375**	759.485	**252**	721.758
13	**375**	759.485	**204**	707.770
14	**355**	752.970	**787**	917.209
15	**475**	801.001	**787**	917.209
16	**528**	820.731	**787**	917.209

CO_2-slicing technique: channels configuration





Channel pair sensitivity at a certain height H is defined as number of valid estimates (percentage from total data set)

Vertical sampling: 100 m
Data set: July 1st, 2008, 00Z

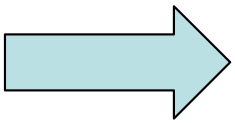
The sensitivities of the first 13 pairs (not employing the channel #787) have the same shape

All pairs have difficulties peaking near the surface; only the last 3 pairs (employing the channel #787) present a weak sensitivity in the first 500m

Revision of CO_2-slicing technique

Use a 11 micron reference channel paired with a CO_2 channel 12.5-14 μm?

Advantages	Disadvantages
- 11 μm channel sees all clouds	- cloud emissivity ratio not unity: could it be modeled?
- May improve detection of low clouds	- channel pairs are not independent
	- subject to surface temperature errors more so than using a channel peaking at ~1 km

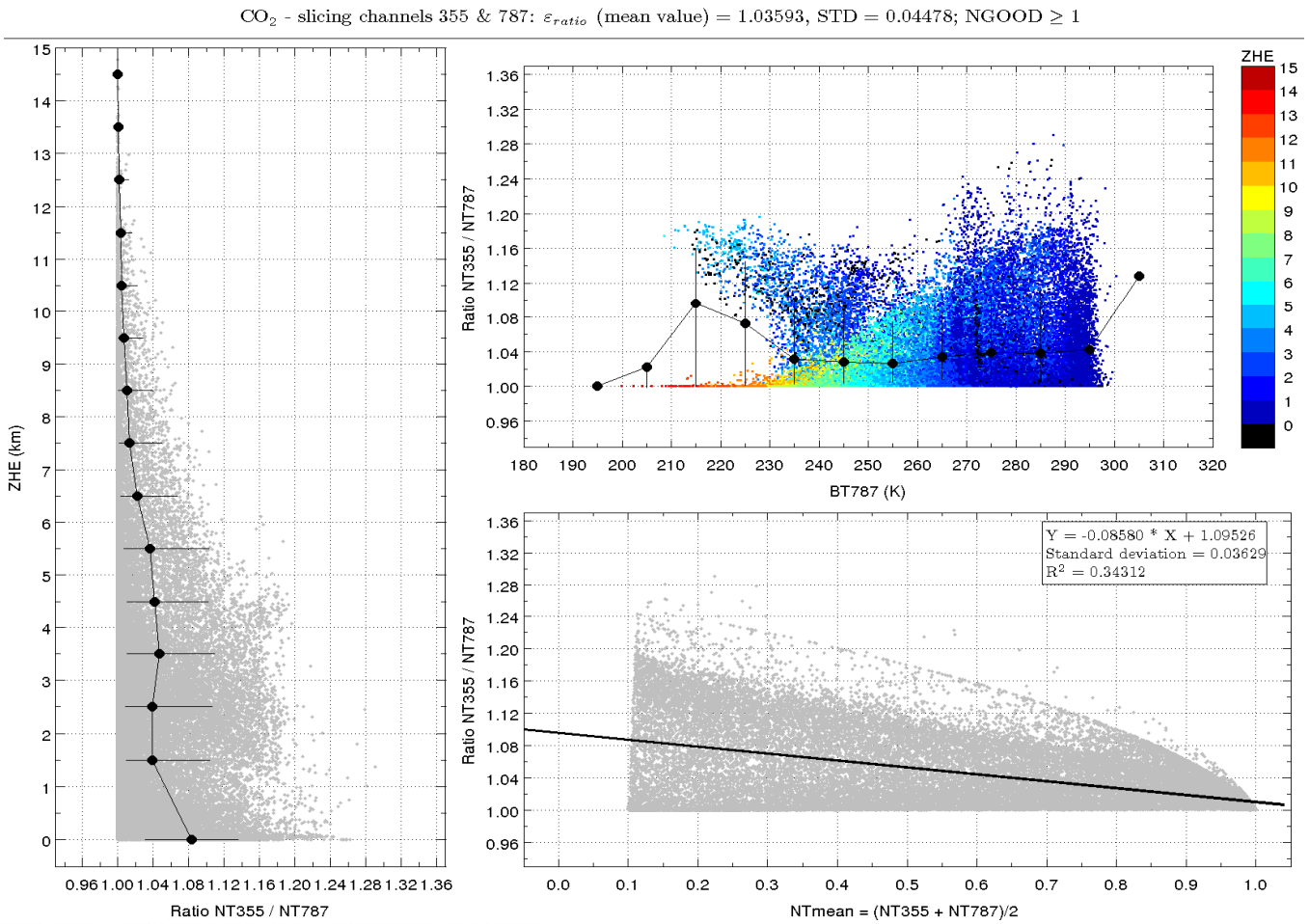


Recent availability of cloudy RTM allows to study the issue

Emissivity ratio considerations

Cloud emissivity ratio could be given by the detected cloud amounts ratio and can be far from unity (Ex: 13.3 / 10.9 µm ratio reaches **1.2**)

11 µm equivalent height vs ratio



Ratio vs BT (11 µm)

Color scale = cloud top height
Black plots = mean ratio and STD for 10 K bins

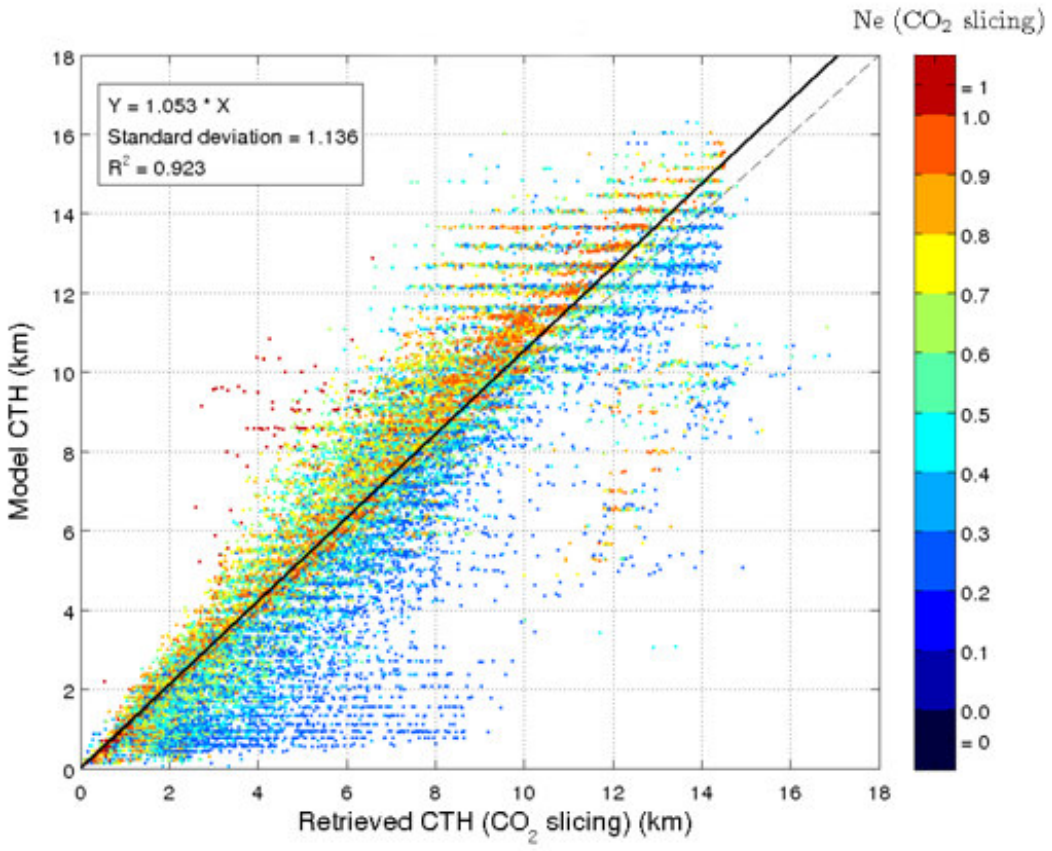
Ratio vs equivalent cloud amount Ne

Emissivity ratio considerations: impact of channel selection

Model output (true) height versus retrieved from simulated radiances

Configuration with 12 channels coupled to a reference profile peaking near the surface	
Channel #	Wavenumber
204	707.770
221	712.661
232	715.862
252	721.758
262	724.742
272	727.752
299	735.298
305	737.152
310	738.704
355	752.970
362	755.237
475	801.001
Reference channel	
787	917.209

Assuming emissivity ratio = 1.0
STD excluding outsiders: 1.14 km



Emissivity ratio considerations: impact of channel selection

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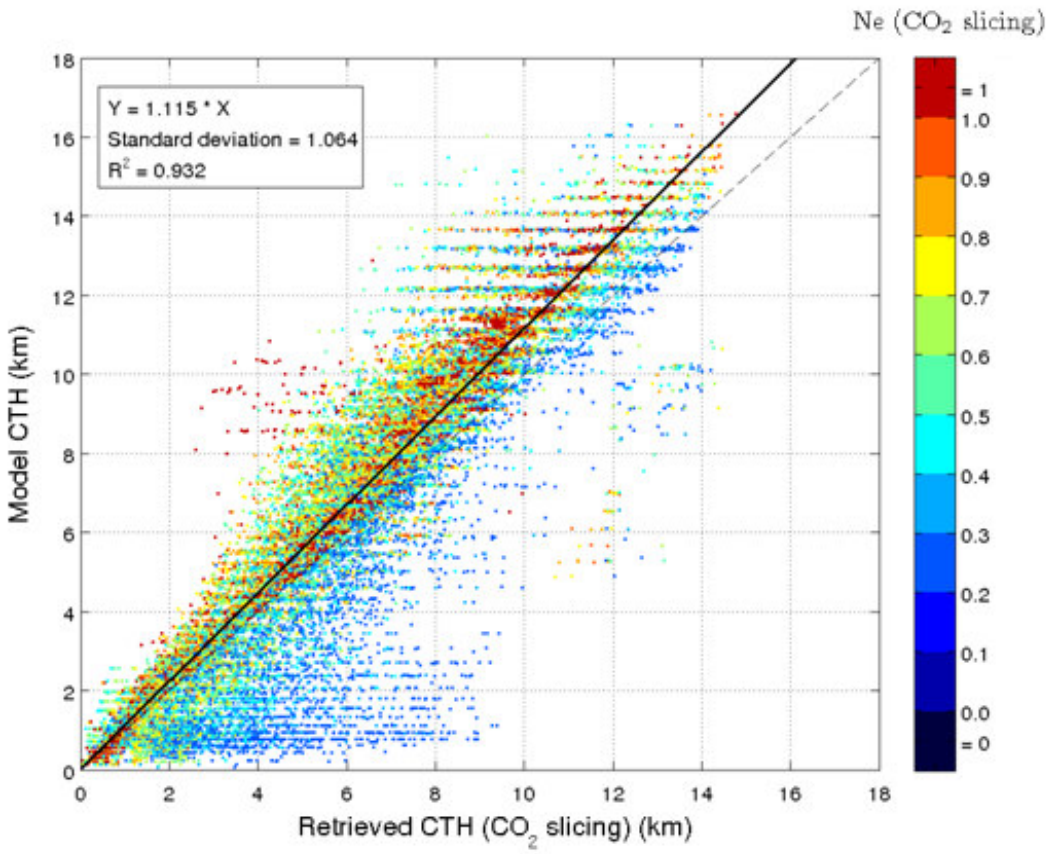
310	738.704
355	752.970
362	755.237
475	801.001
Reference channel	
787	917.209

Emissivity ratio fitted to Ne found in first iteration of CO_2-slicing
STD excluding outsiders: 1.06 km



Emissivity ratio considerations: impact of channel selection

Model output (true) height versus retrieved from simulated radiances

Chosen configuration: 13 pairs of coupled channels In narrow limited range				
	Channel		Reference channel	
Pair #	#	cm^{-1}	#	cm^{-1}
1	**204**	707.770	**252**	721.758
2	**221**	712.661	**262**	724.742
3	**232**	715.862	**272**	727.752
4	**252**	721.758	**299**	735.298
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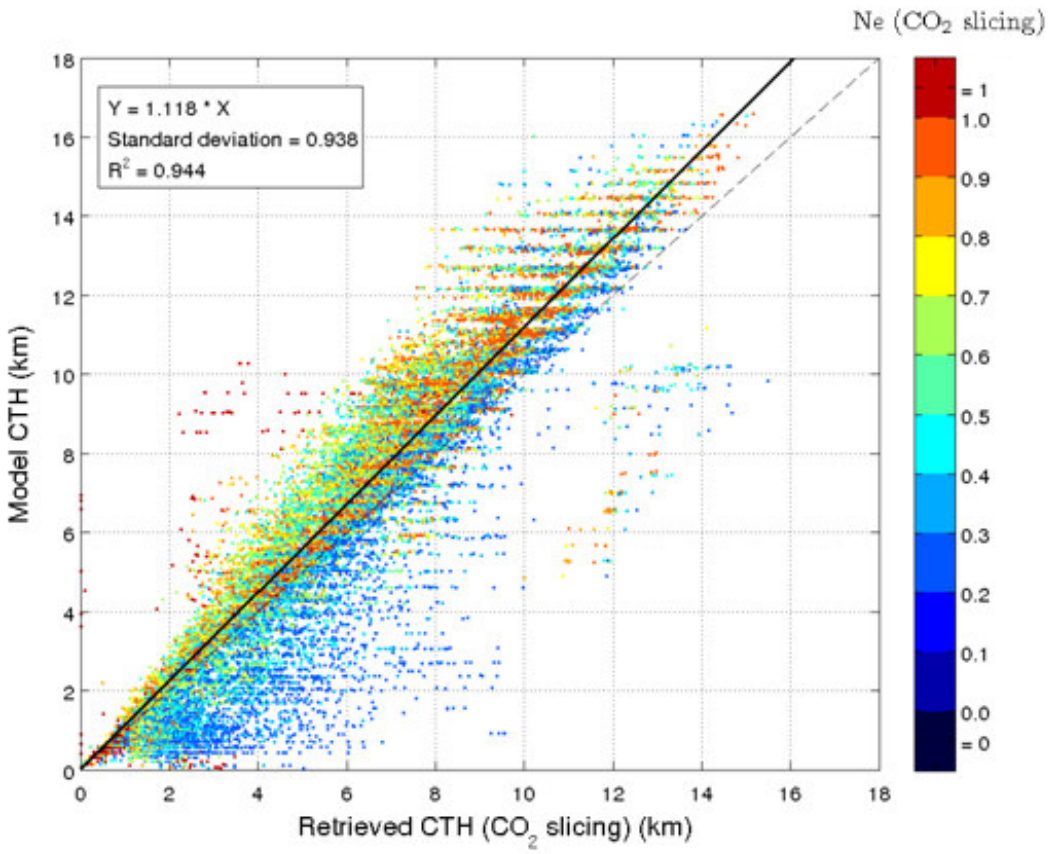
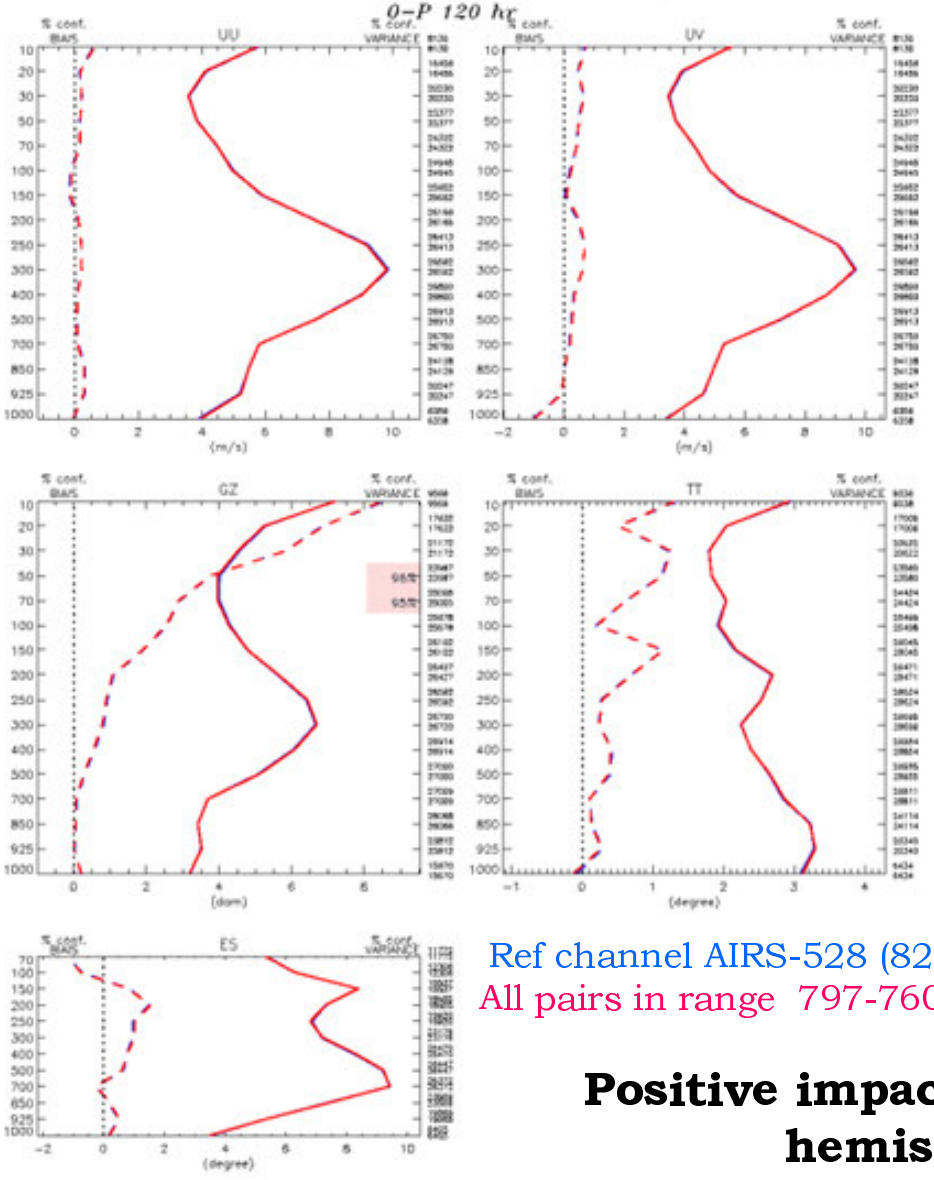
11	**362**	755.237	**262**	724.742
12	**375**	759.485	**252**	721.758
13	**375**	759.485	**204**	707.770

All channels on range 707 – 760 cm^{-1}
STD excluding outsiders: 0.94 km

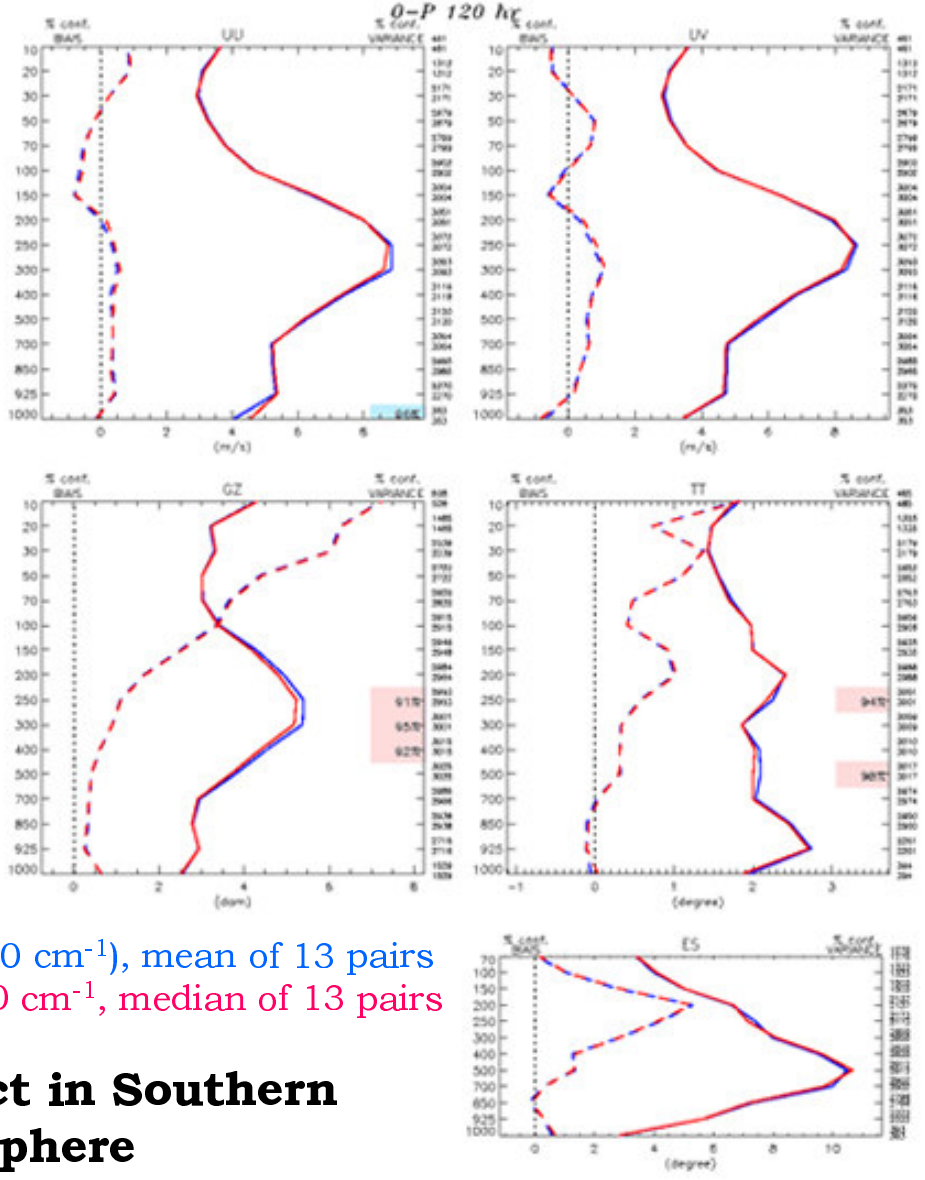


Assimilation impact test on channel selection: 120 h forecast vs observations (Alain Beaulne)

Global



Southern Hemisphere



Ref channel AIRS-528 (820 cm^{-1}), mean of 13 pairs
All pairs in range 797-760 cm^{-1}, median of 13 pairs

Positive impact in Southern hemisphere

Validation results

Comparison model vs retrieval (from observed and simulated AIRS radiances):

- Cloud top height (CTH) distributions

- Cloud amount (Ne) distributions

- CTH bias model vs retrieval (from simulations) - cancellation of biases induced by retrieval technique

- validation confirmed by CALIPSO comparisons

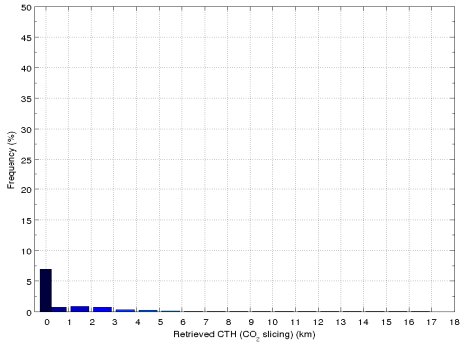
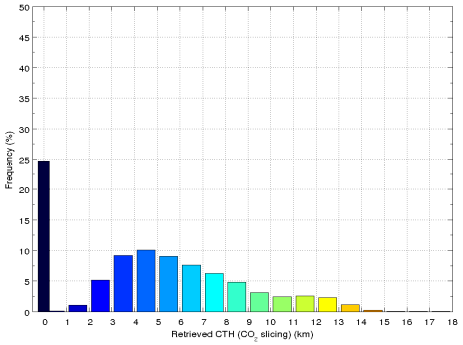
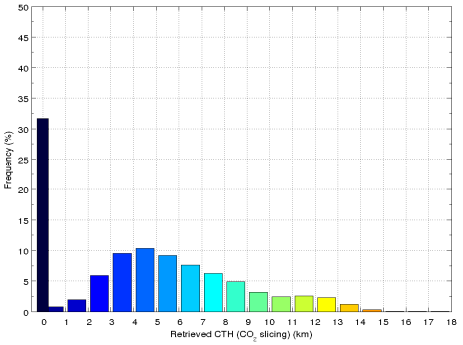
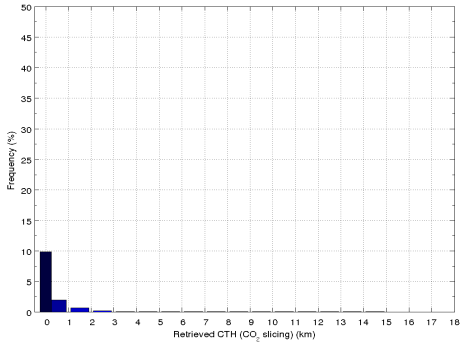
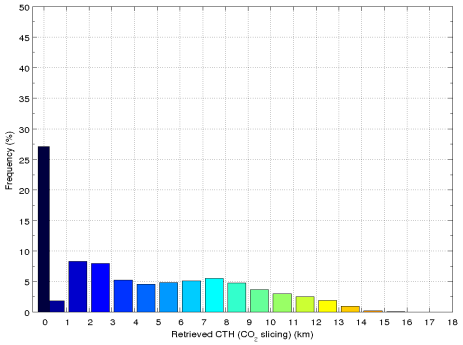
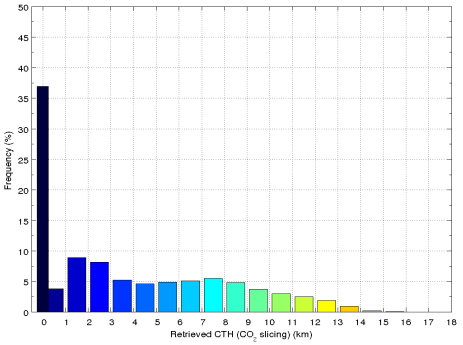
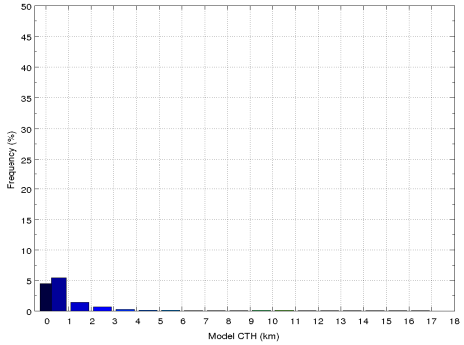
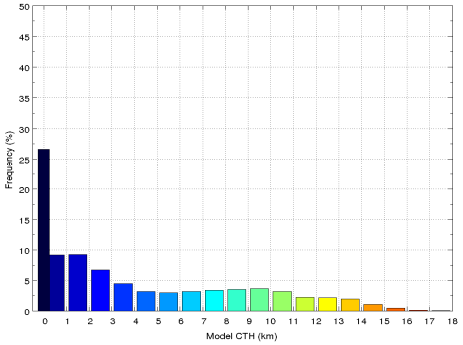
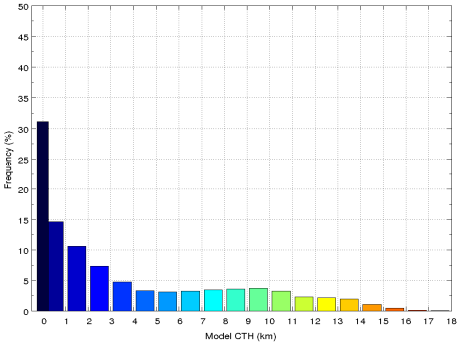
Goal: provide meaningful information to modeler on cloud parameters and a tool for evaluation

Note: when CO_2-slicing fails (~10 % of cases) the effective height is used by matching window temperature to guess temperature profile, assuming overcast.

The following results concerns 24h data on July14th, 2008

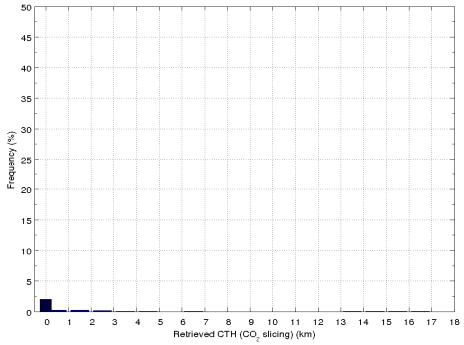
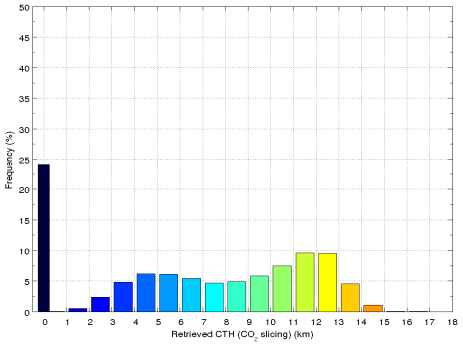
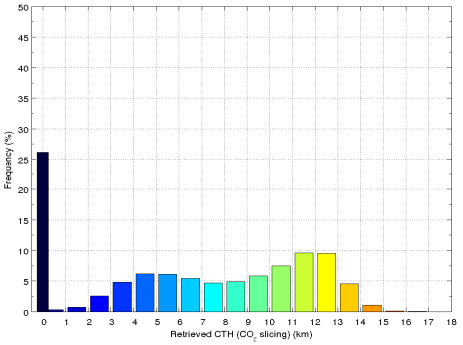
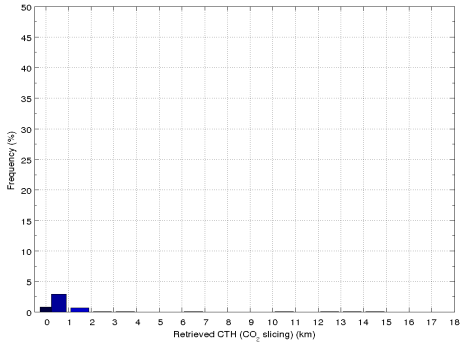
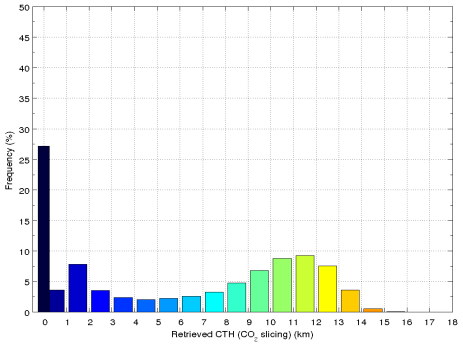
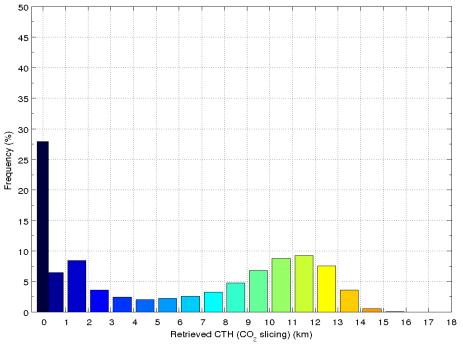
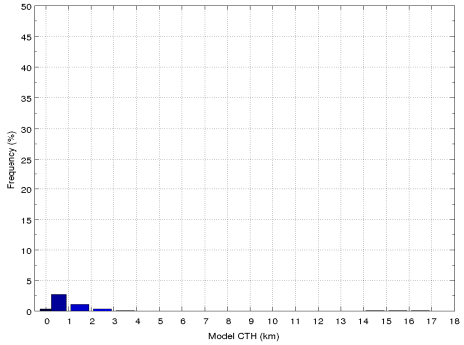
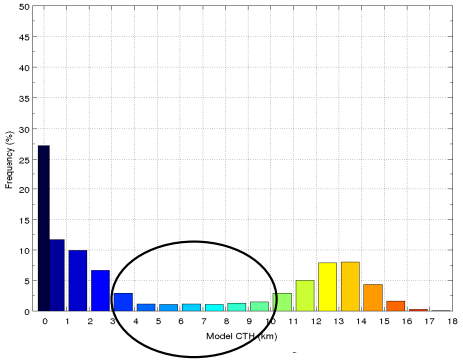
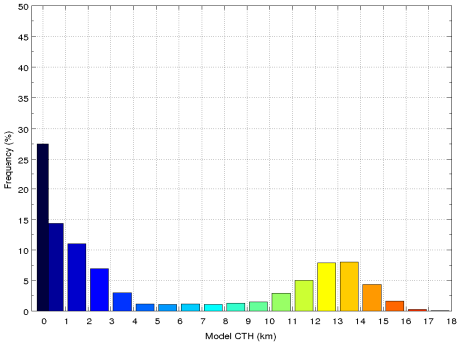
Validation results: cloud top height distribution

Global data: relatively good agreement for mid and high level clouds

	CO_2-slicing fails	CO_2-slicing OK	Total
Retrieved from real data			
Retrieved from simulated data			
Directly from model output			

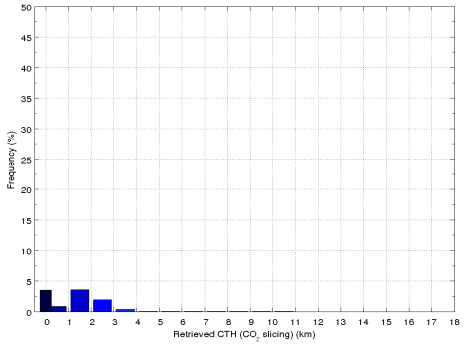
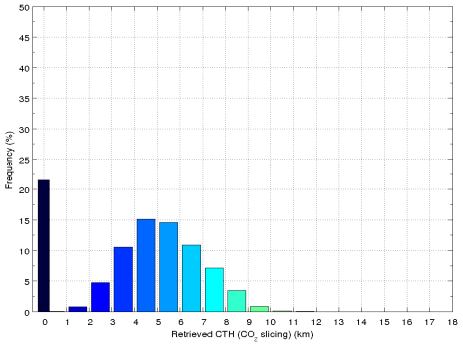
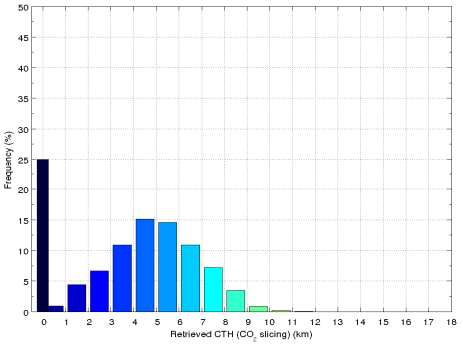
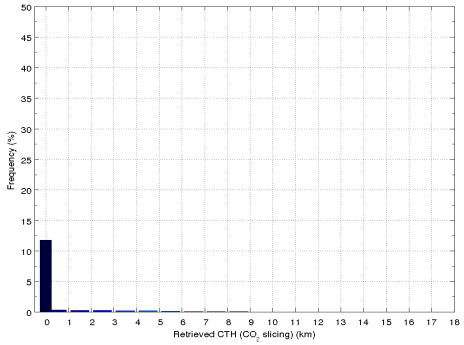
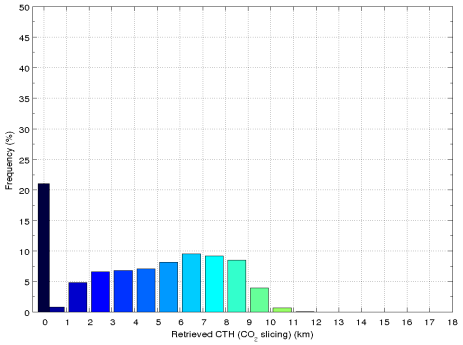
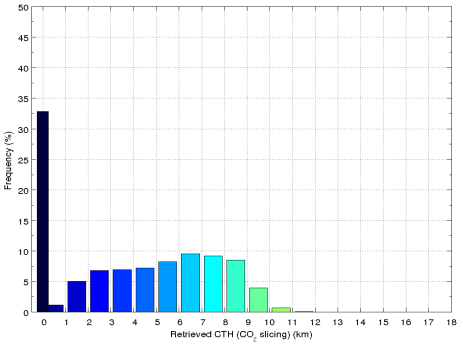
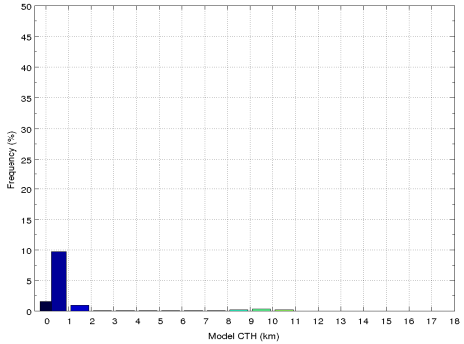
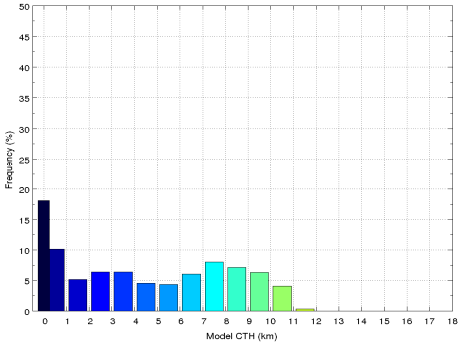
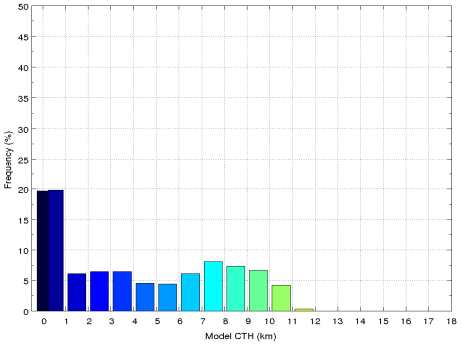
Validation results: cloud top height distribution

15˚S – 15˚N: lack of mid level clouds (3 – 8 km) in model

	CO_2-slicing fails	CO_2-slicing OK	Total
Retrieved from real data			
Retrieved from simulated data			
Directly from model output			

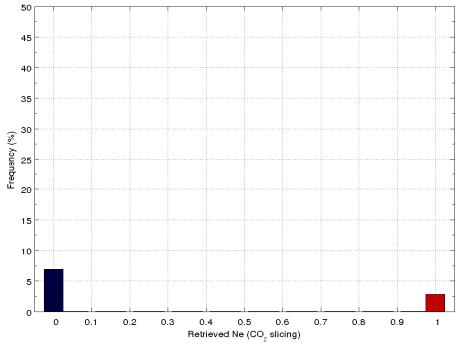
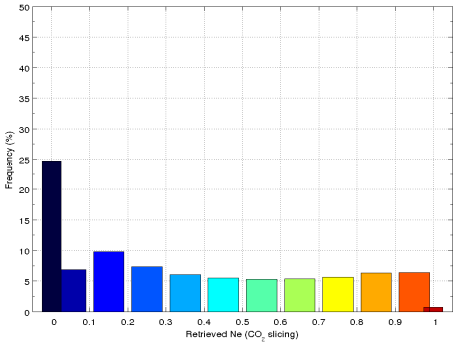
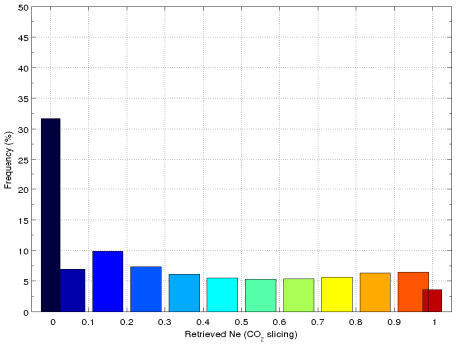
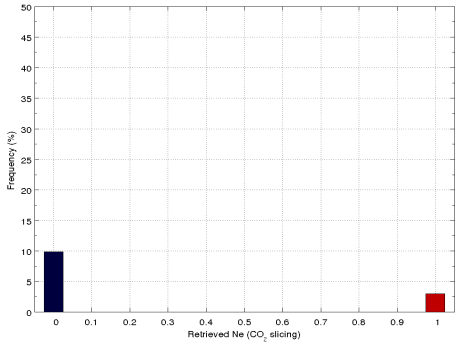
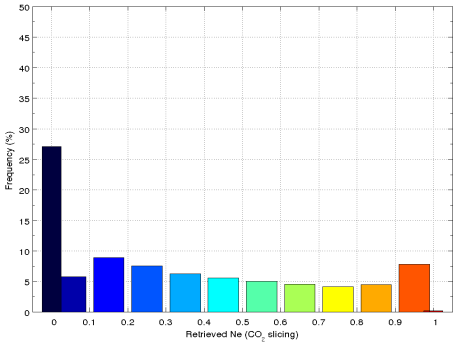
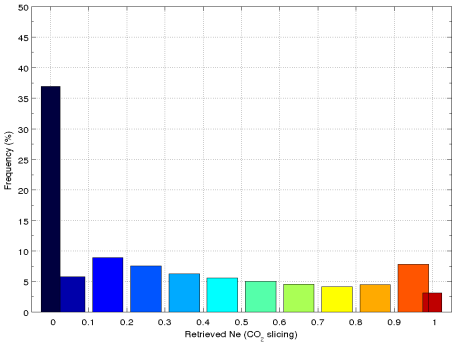
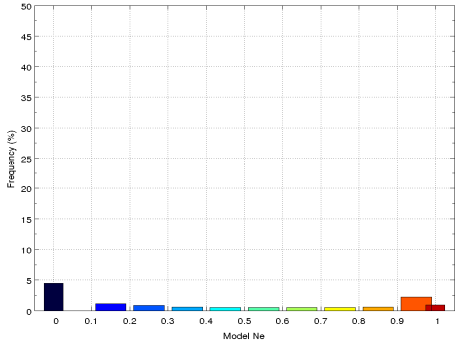
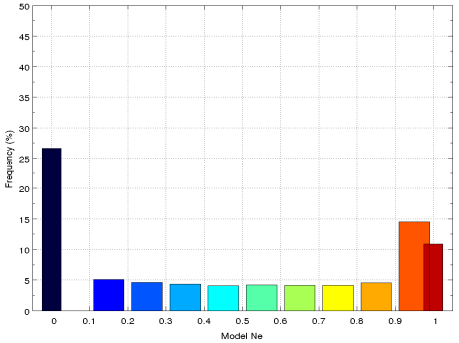
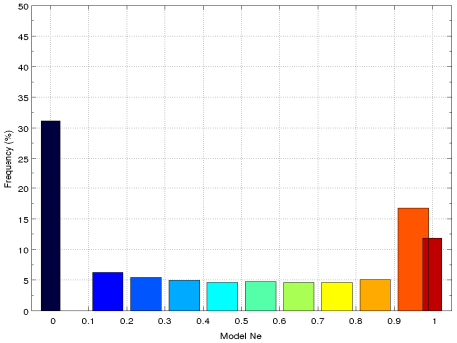
Validation results: cloud top height distribution

Arctic (65˚– 90˚N): model distribution is too flat

	CO_2-slicing fails	CO_2-slicing OK	Total
Retrieved from real data			
Retrieved from simulated data			
Directly from model output			

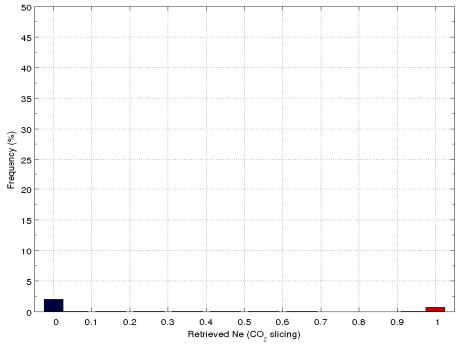
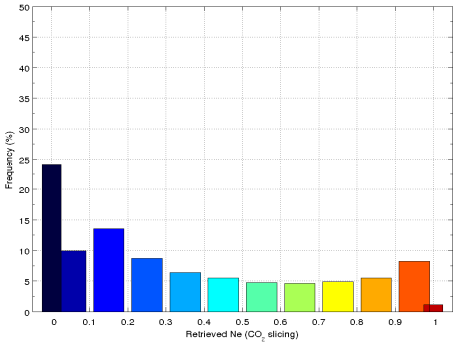
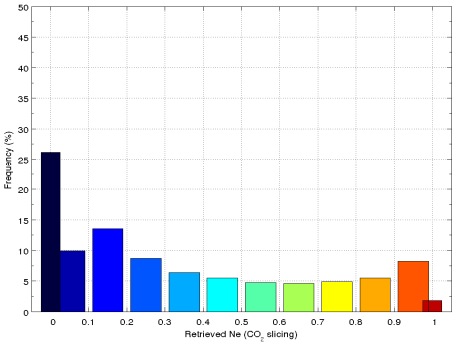
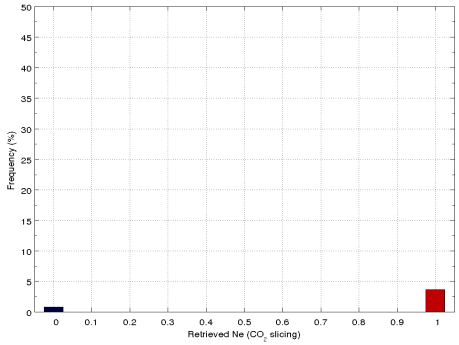
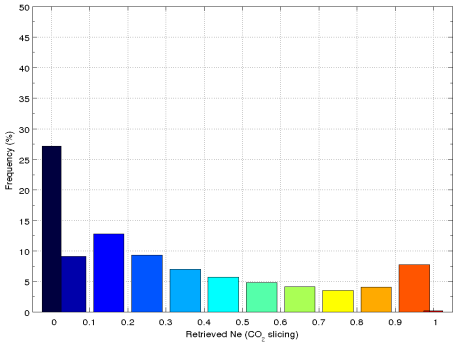
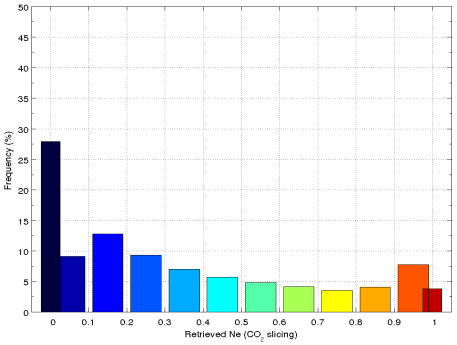
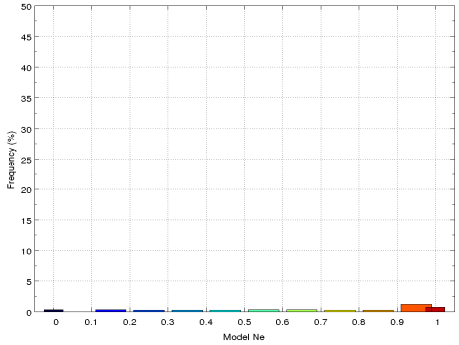
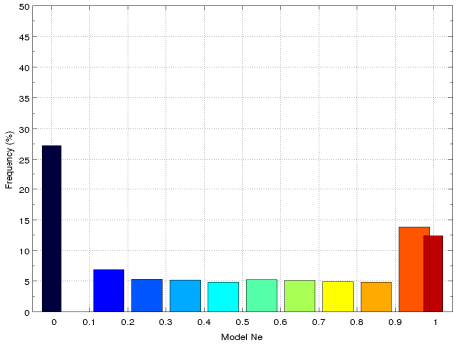
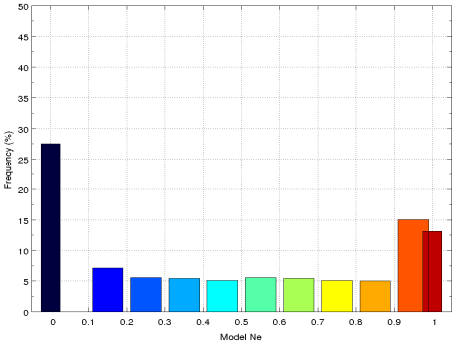
Validation results: cloud amount distribution

Global data: Good overall agreement except high cloud amounts (Ne > 0.9)

	CO_2-slicing fails	CO_2-slicing OK	Total
Retrieved from real data			
Retrieved from simulated data			
Directly from model output			

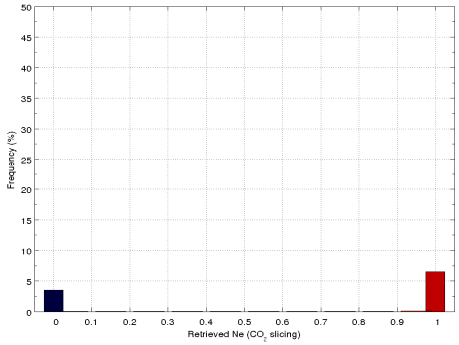
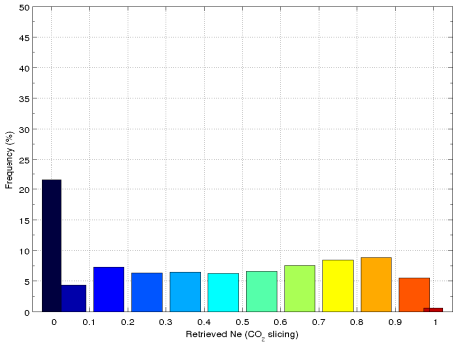
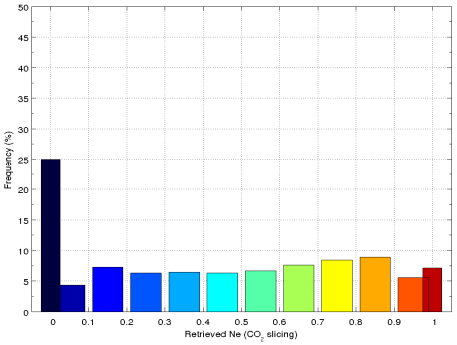
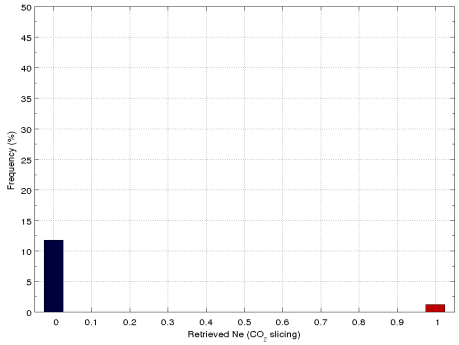
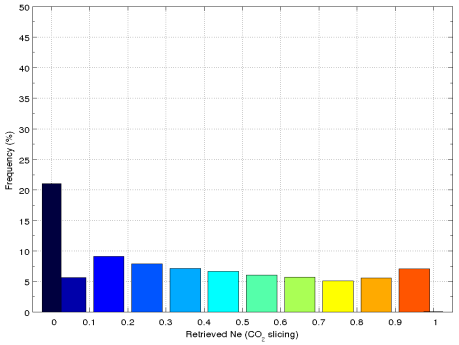
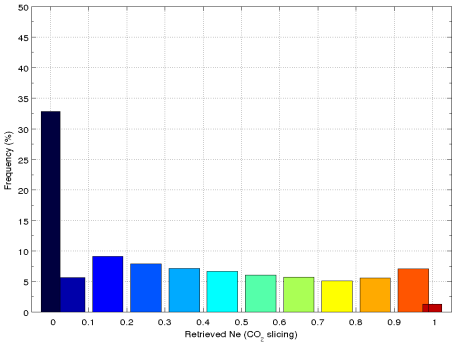
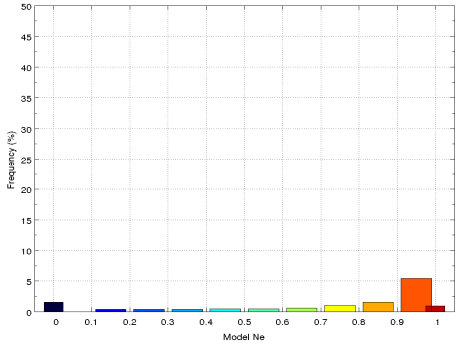
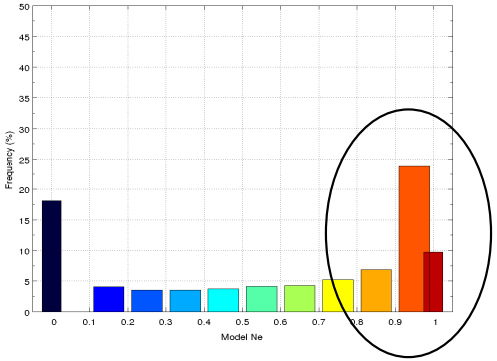
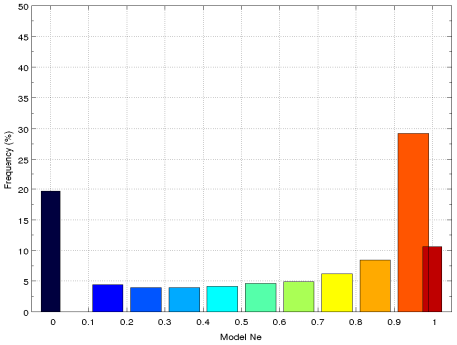
Validation results: cloud amount distribution

15˚S – 15˚N: Good overall agreement except high cloud amounts (Ne > 0.9)

	CO_2-slicing fails	CO_2-slicing OK	Total
Retrieved from real data			
Retrieved from simulated data			
Directly from model output			

Validation results: cloud amount distribution

Arctic (65˚– 90˚N): Higher frequency of cloud amounts (Ne > 0.9) in model

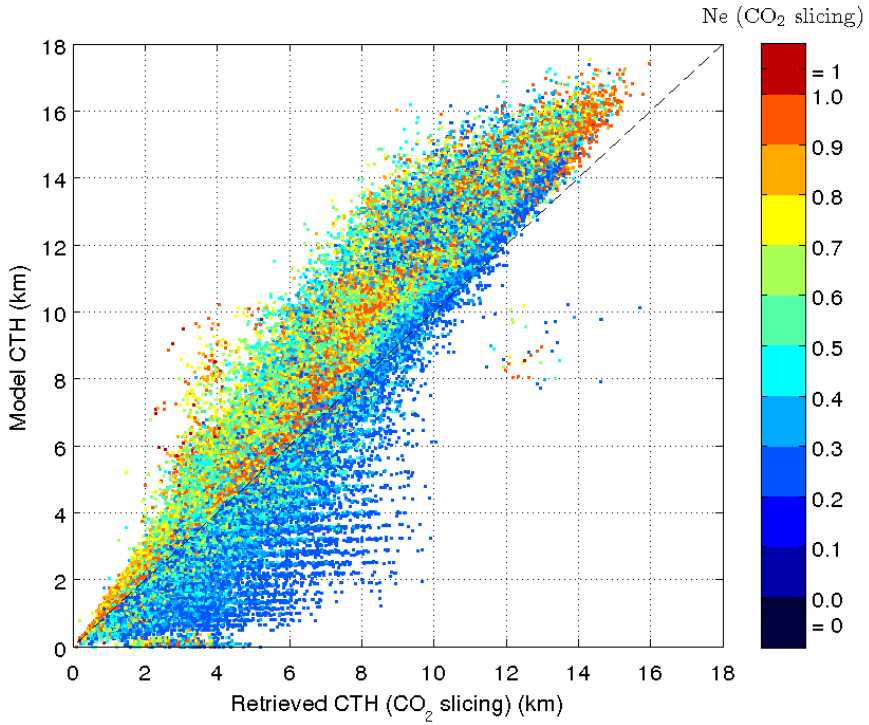
	CO_2-slicing fails	CO_2-slicing OK	Total
Retrieved from real data			
Retrieved from simulated data			
Directly from model output			

Validation results: cloud top height bias

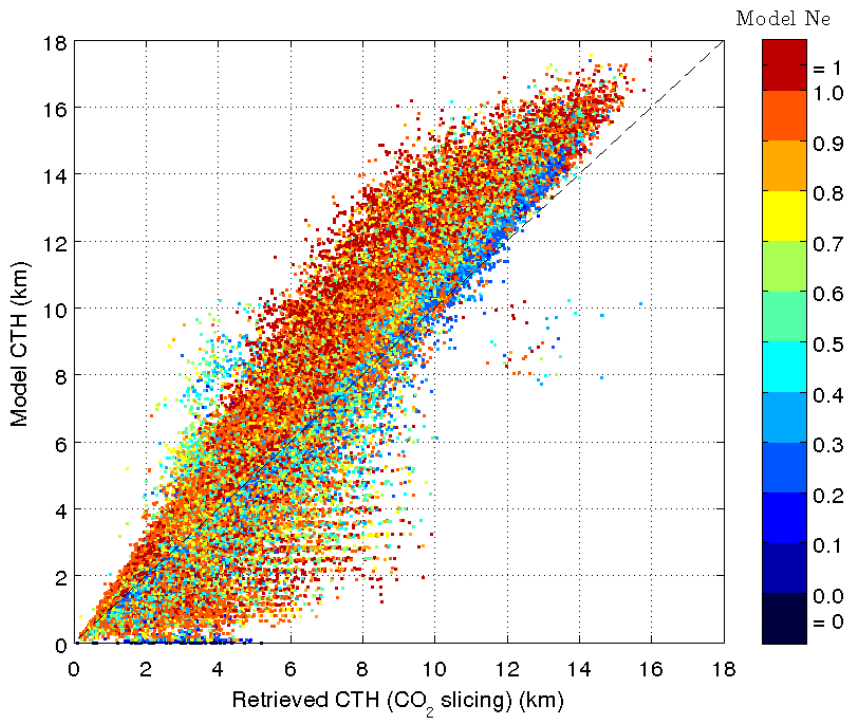
Model CTH vs retrieved CTH from simulated AIRS radiances

Global data

Plot color: retrieved cloud amount Ne



Plot color: model cloud amount Ne

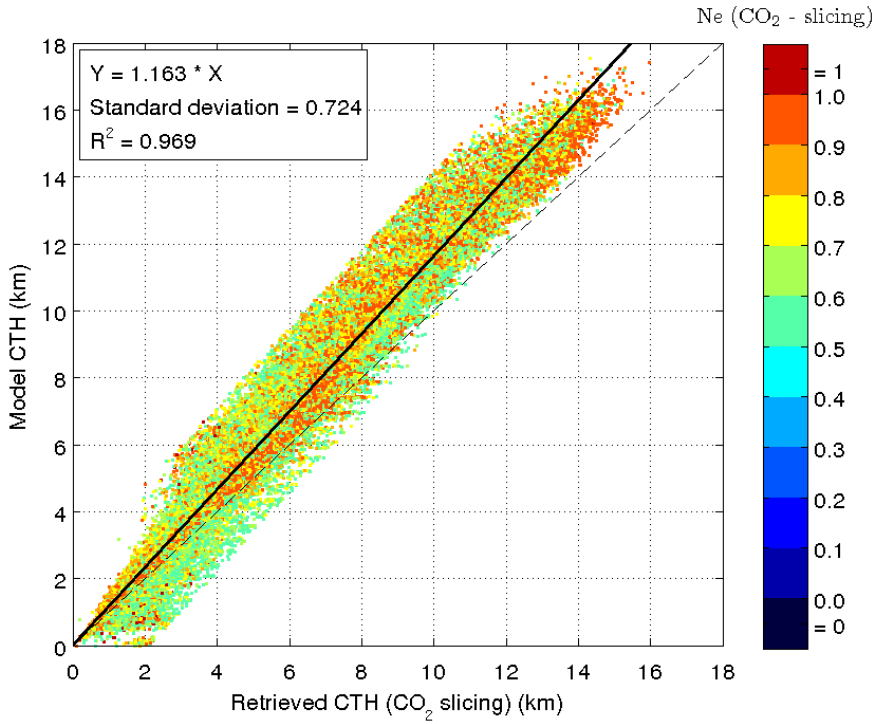


Validation results: cloud top height bias

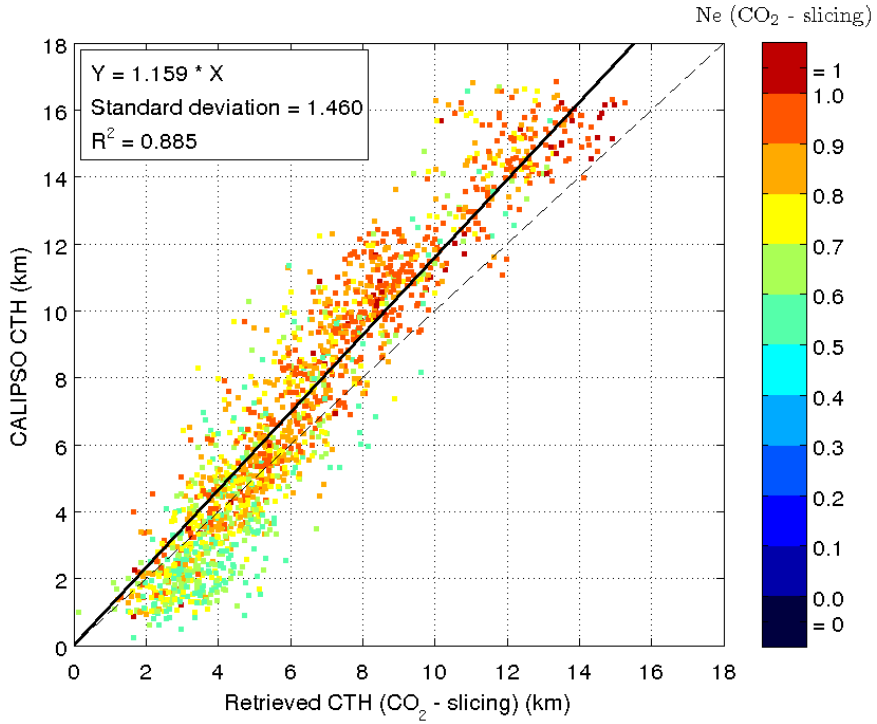
Model CTH vs retrieved CTH from simulated AIRS radiances

Global data

Model CTH vs retrieved CTH
from simulated AIRS radiances



CALIPSO CTH vs retrieved CTH
from real AIRS radiances



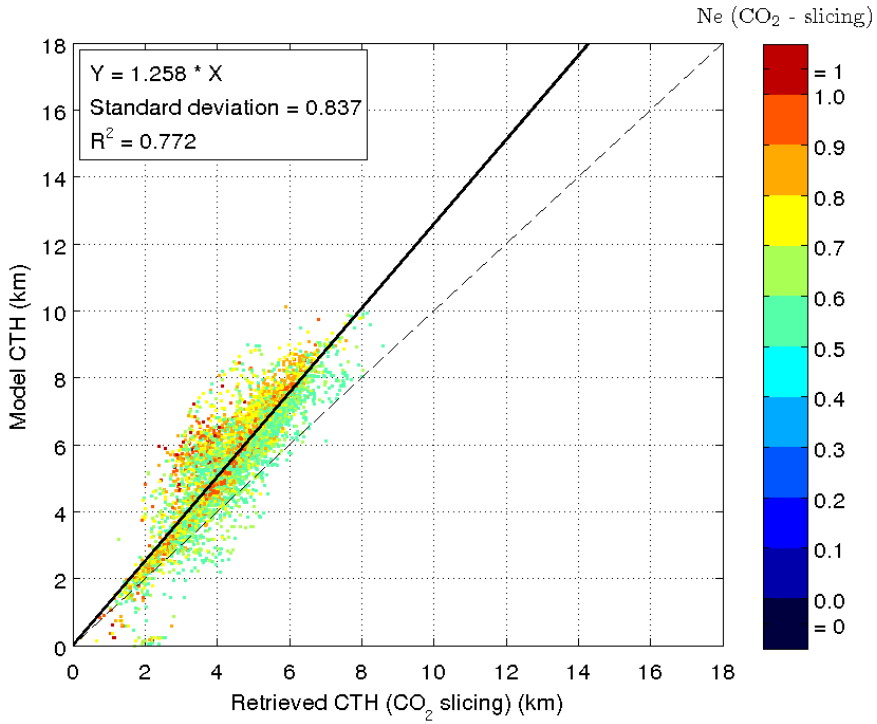
Remarkable similitude in dynamic range and bias attributed to CO_2 slicing technique. Implies definition of model height OK.

Validation results: cloud top height bias

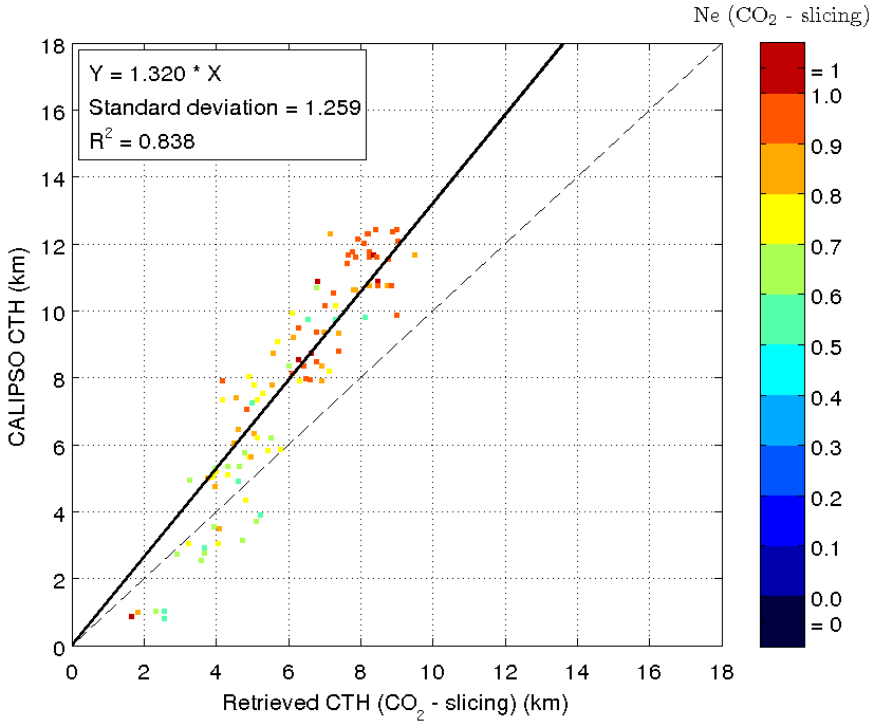
Model CTH vs retrieved CTH from simulated AIRS radiances

Antarctic: 90˚S – 65˚S

Model CTH vs retrieved CTH
from simulated AIRS radiances



CALIPSO CTH vs retrieved CTH
from real AIRS radiances

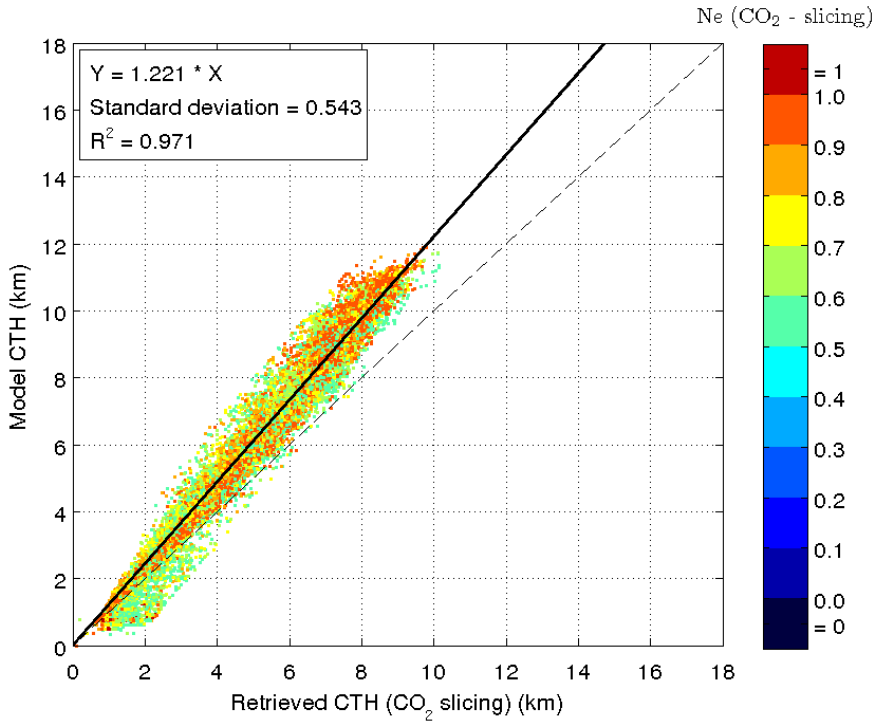


Validation results: cloud top height bias

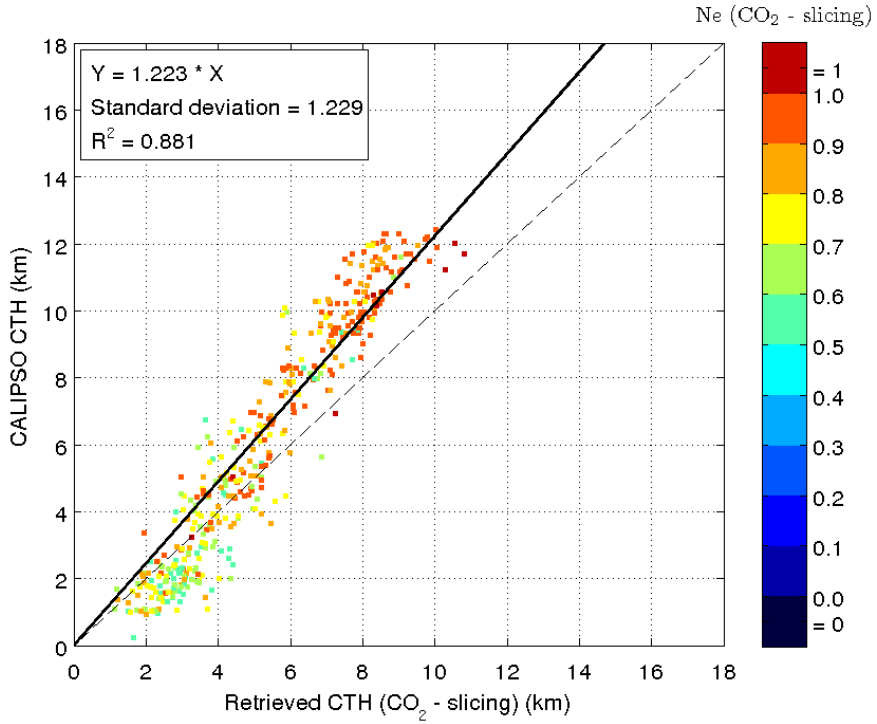
Model CTH vs retrieved CTH from simulated AIRS radiances

65˚S – 40˚S

Model CTH vs retrieved CTH
from simulated AIRS radiances



CALIPSO CTH vs retrieved CTH
from real AIRS radiances

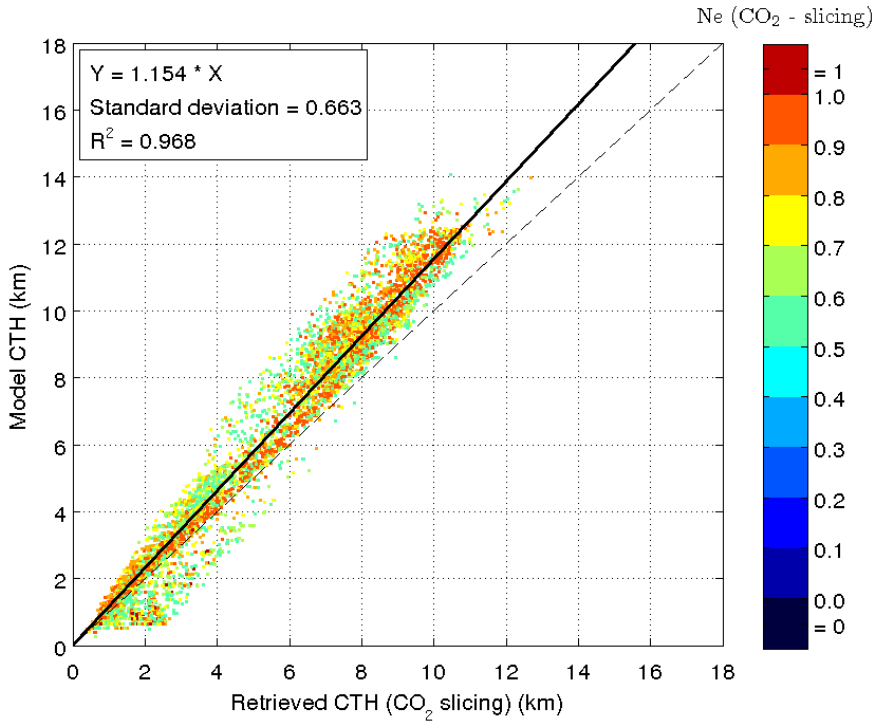


Validation results: cloud top height bias

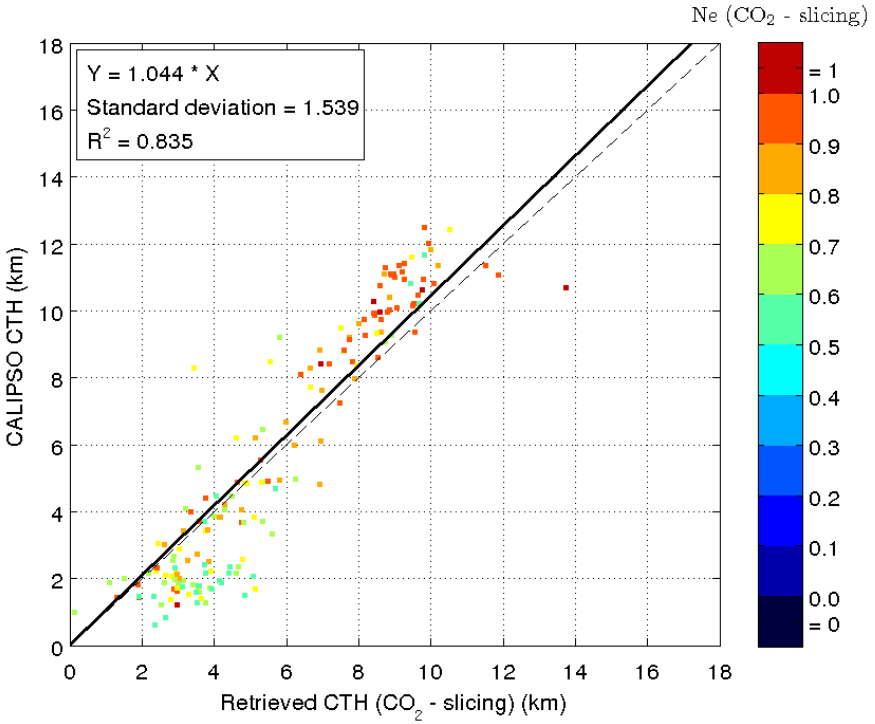
Model CTH vs retrieved CTH from simulated AIRS radiances

40˚S – 15˚S

Model CTH vs retrieved CTH
from simulated AIRS radiances



CALIPSO CTH vs retrieved CTH
from real AIRS radiances

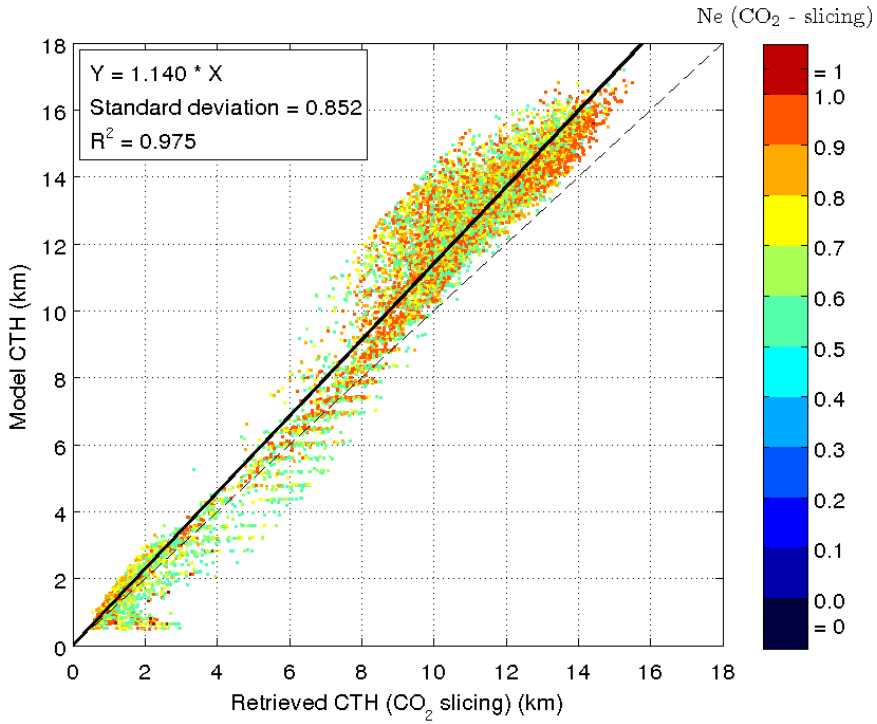


Validation results: cloud top height bias

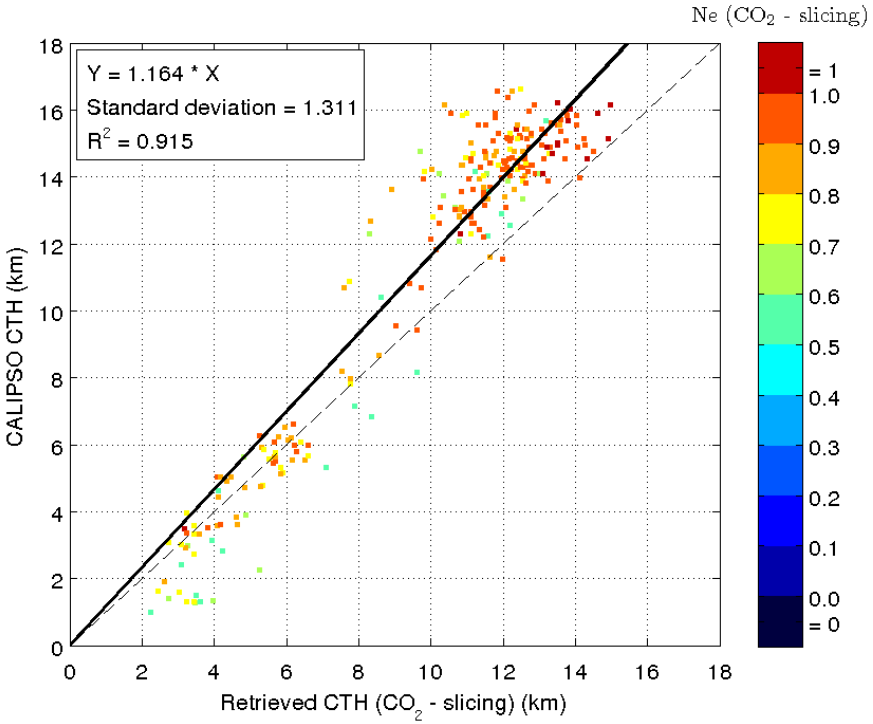
Model CTH vs retrieved CTH from simulated AIRS radiances

15˚S – 15˚N

Model CTH vs retrieved CTH
from simulated AIRS radiances



CALIPSO CTH vs retrieved CTH
from real AIRS radiances

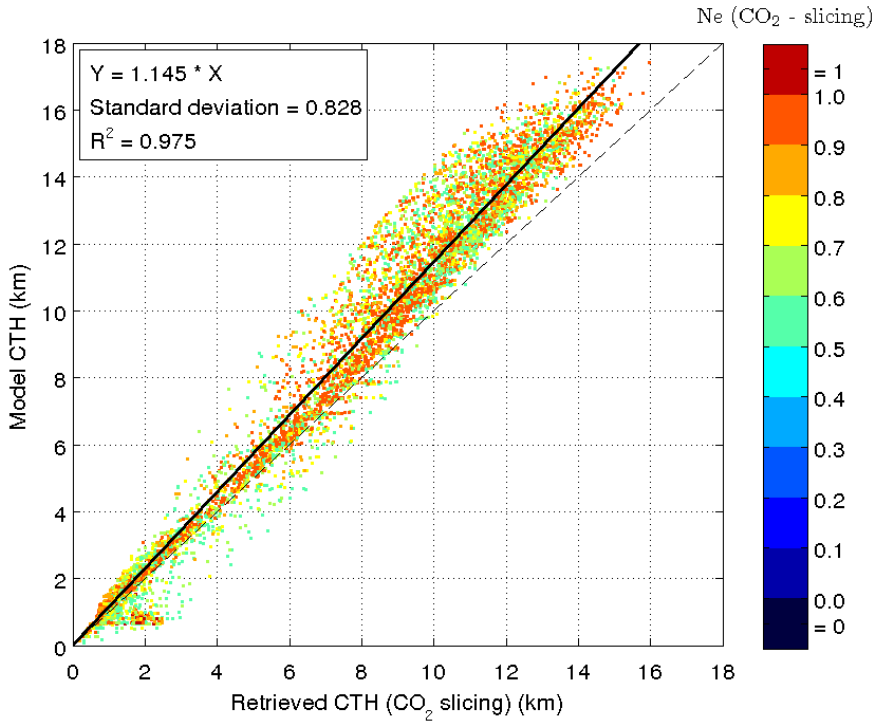


Validation results: cloud top height bias

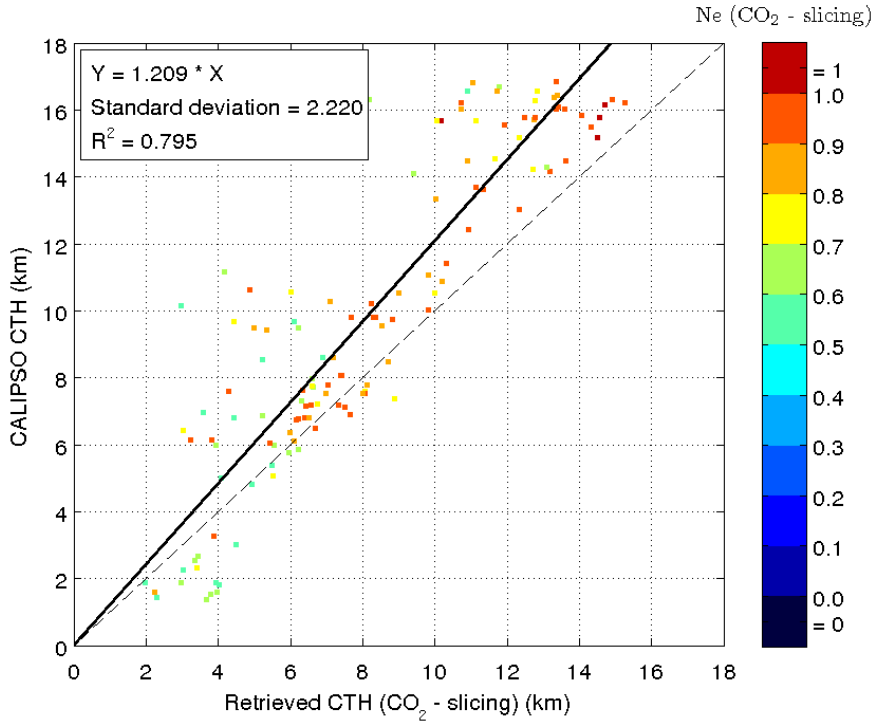
Model CTH vs retrieved CTH from simulated AIRS radiances

15˚N – 40˚N

Model CTH vs retrieved CTH
from simulated AIRS radiances



CALIPSO CTH vs retrieved CTH
from real AIRS radiances

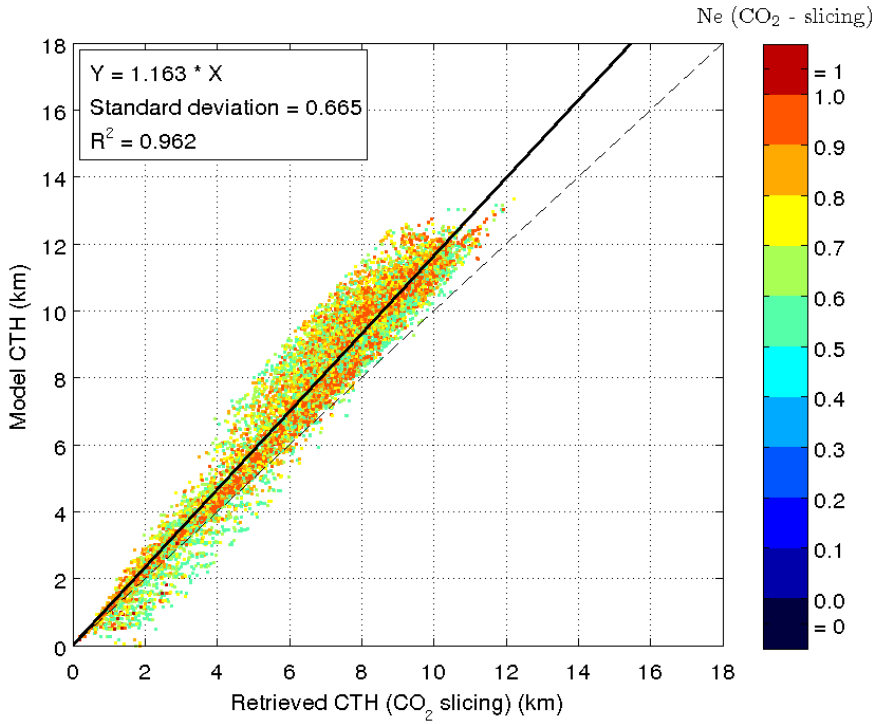


Validation results: cloud top height bias

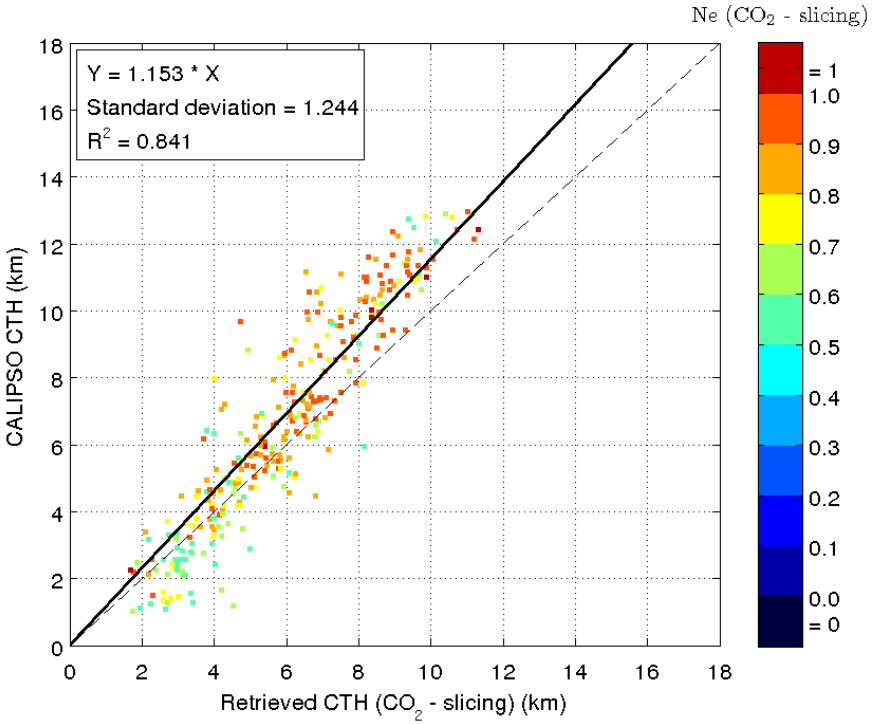
Model CTH vs retrieved CTH from simulated AIRS radiances

40˚N – 65˚N

Model CTH vs retrieved CTH
from simulated AIRS radiances



CALIPSO CTH vs retrieved CTH
from real AIRS radiances

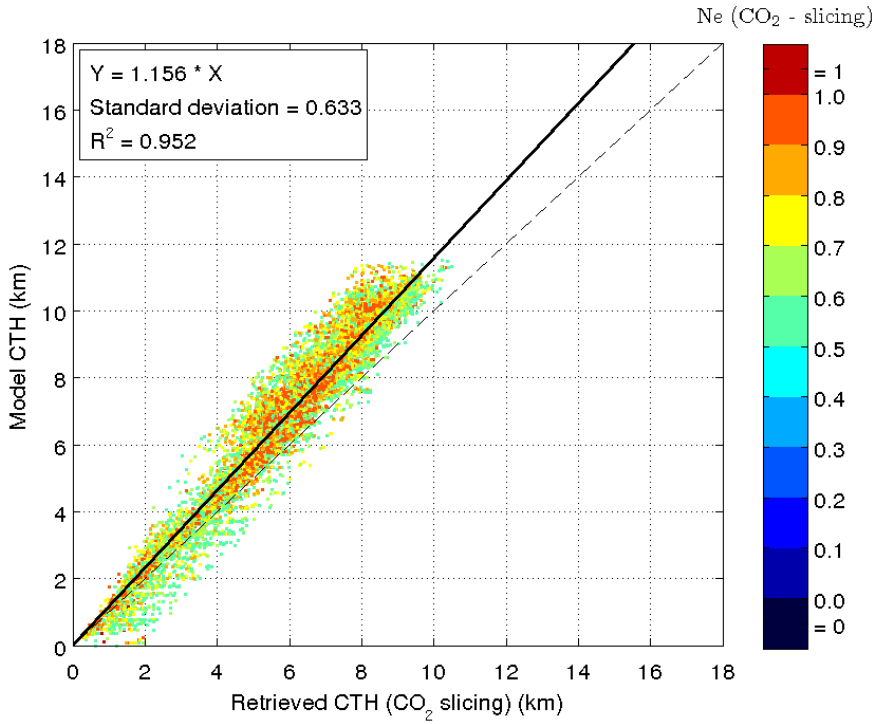


Validation results: cloud top height bias

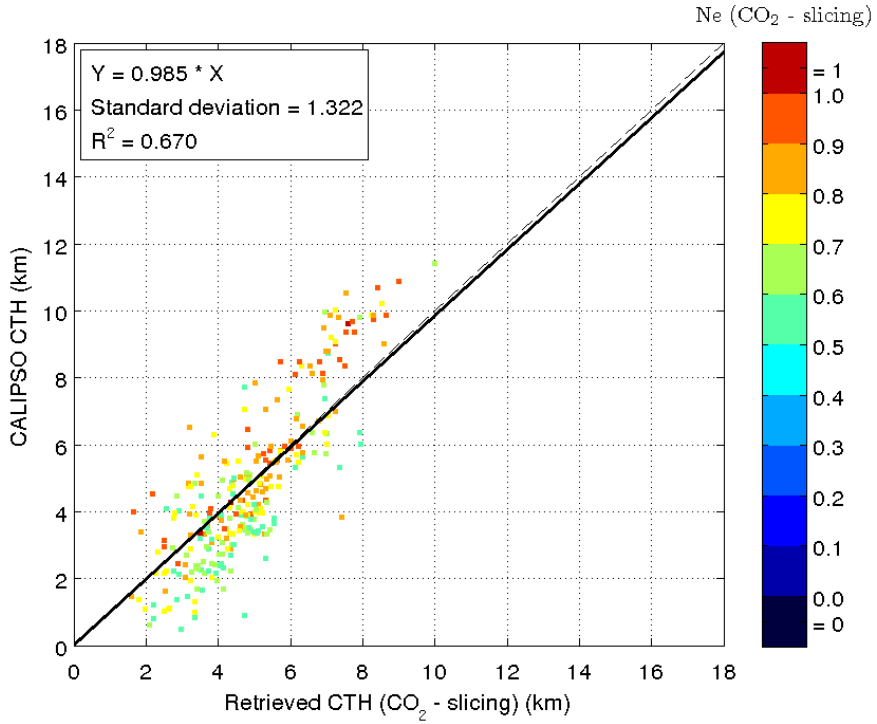
Model CTH vs retrieved CTH from simulated AIRS radiances

Arctic: 65˚N – 90˚N

Model CTH vs retrieved CTH
from simulated AIRS radiances



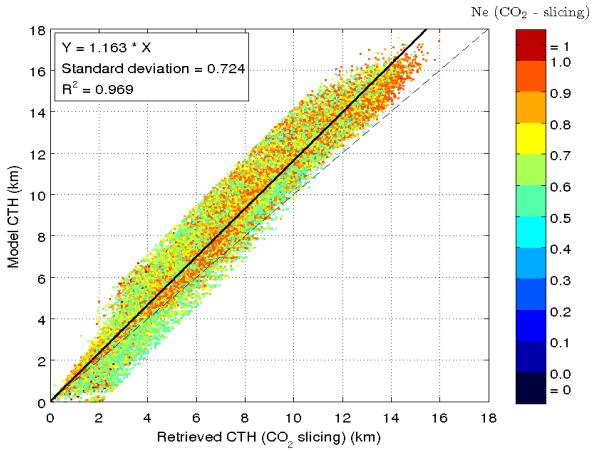
CALIPSO CTH vs retrieved CTH
from real AIRS radiances



Validation results: cloud top height bias

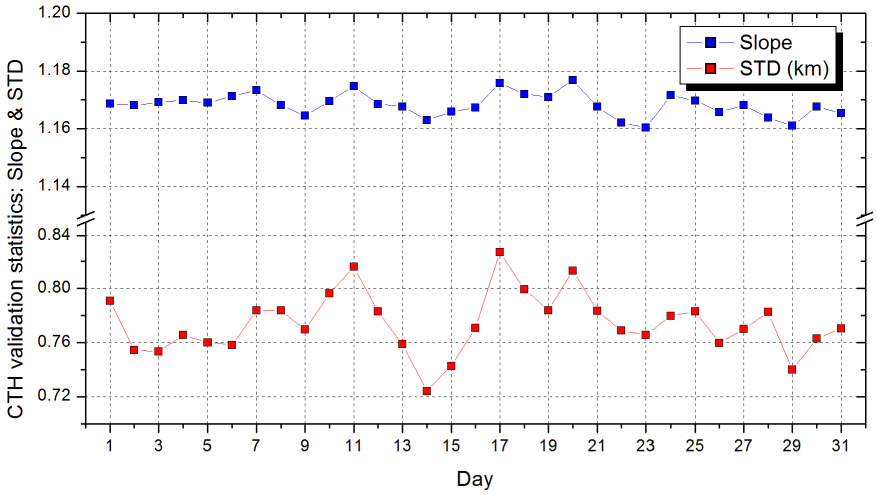
The bias model vs retrieved is quite stable. Only cloud amounts superior to 0.5 were considered.

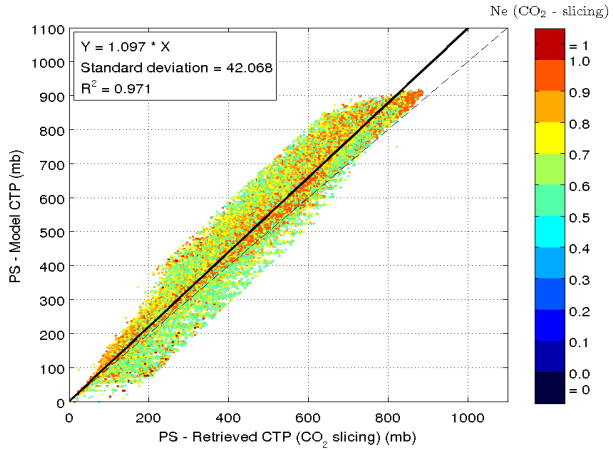
2008/07/14



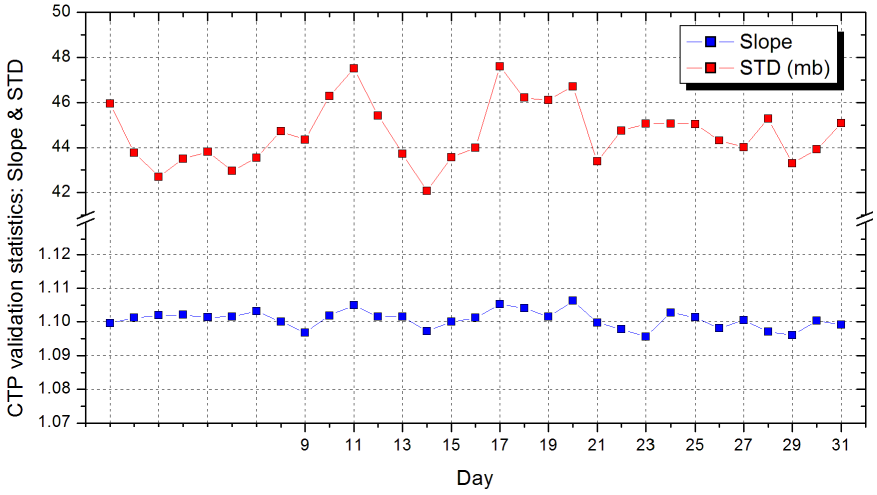
CTH bias

Daily values for July 2008





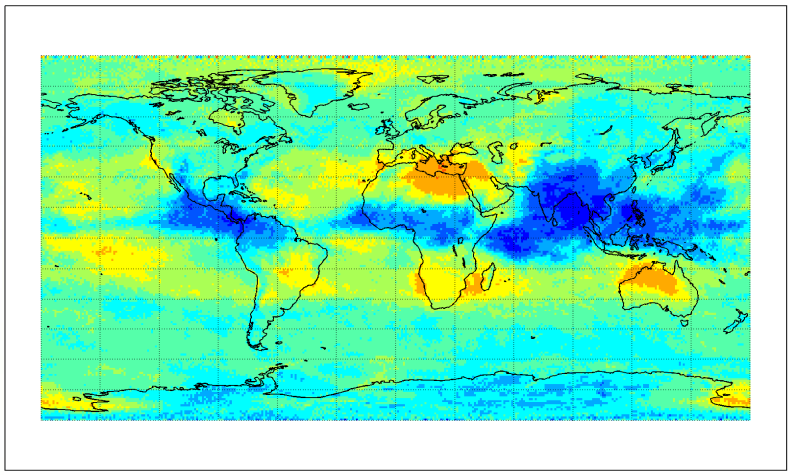
CTP bias



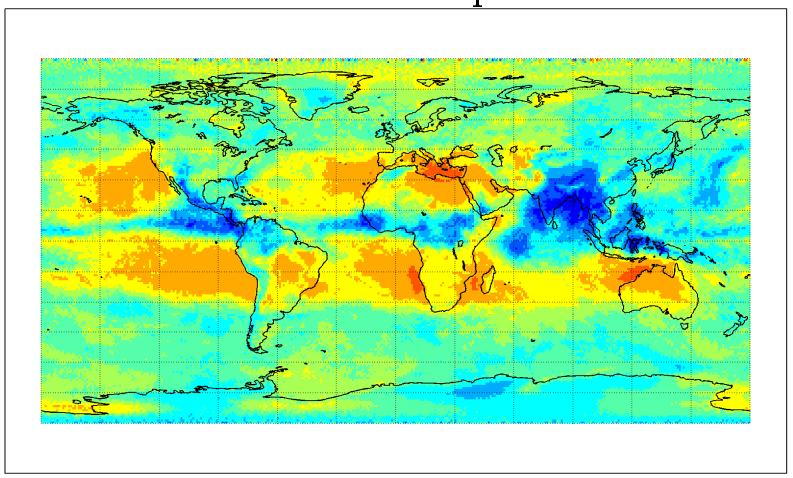
Validation results: monthly maps of cloud parameters

Cloud Top Pressure CTP (July 2008)

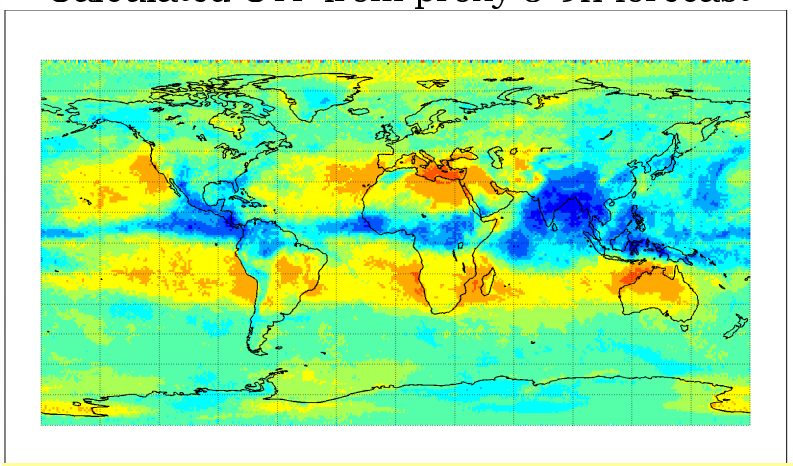
Observed CTP



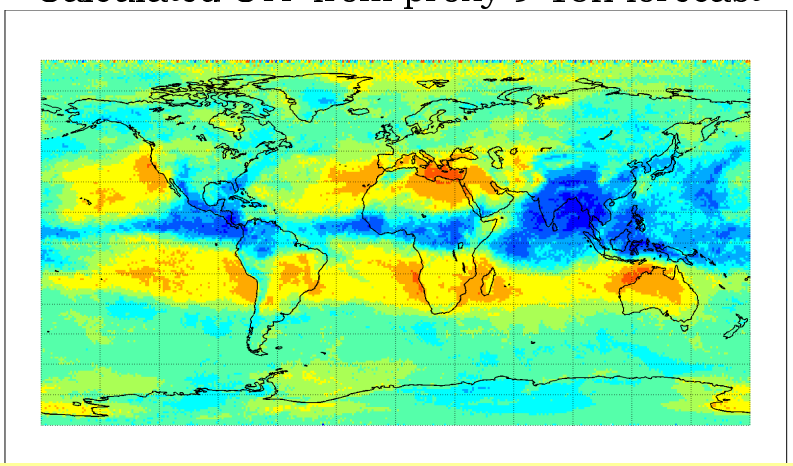
Direct model output CTP



Calculated CTP from proxy 3-9h forecast



Calculated CTP from proxy 9-15h forecast

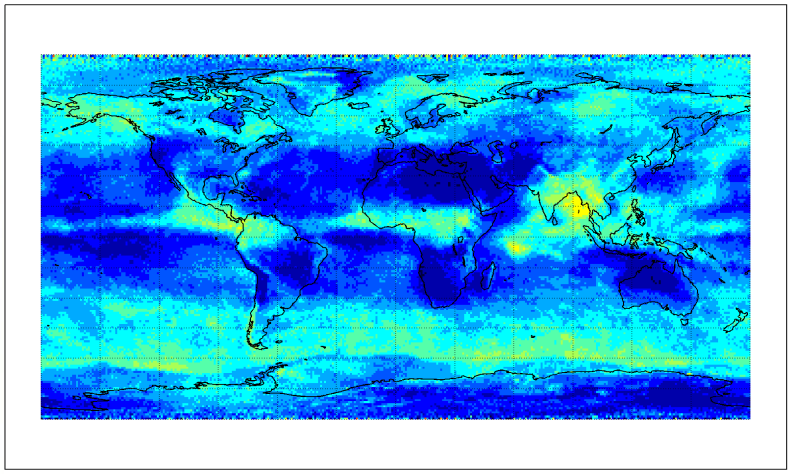


Good overall agreement between observed, calculated and direct model output CTP.
Differences most notable for low clouds on west of continents.

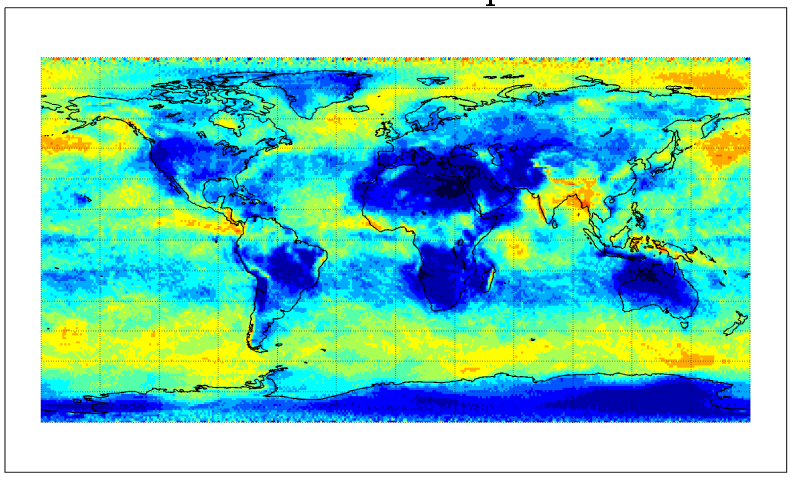
Validation results: monthly maps of cloud parameters

Cloud Amount Ne (July 2008)

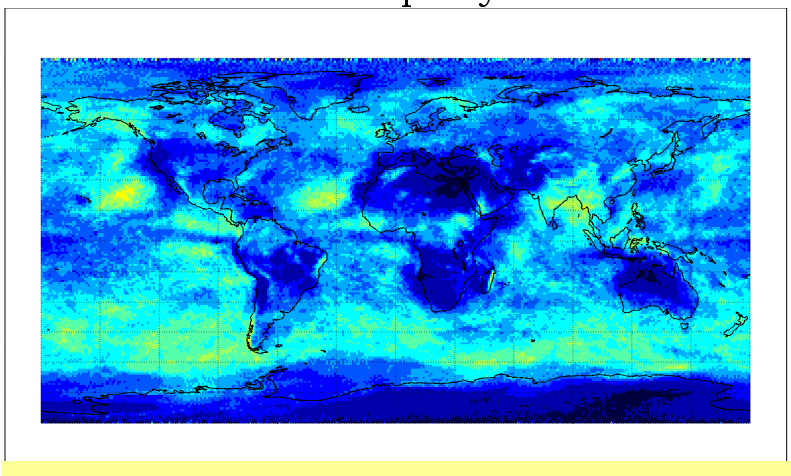
Observed Ne



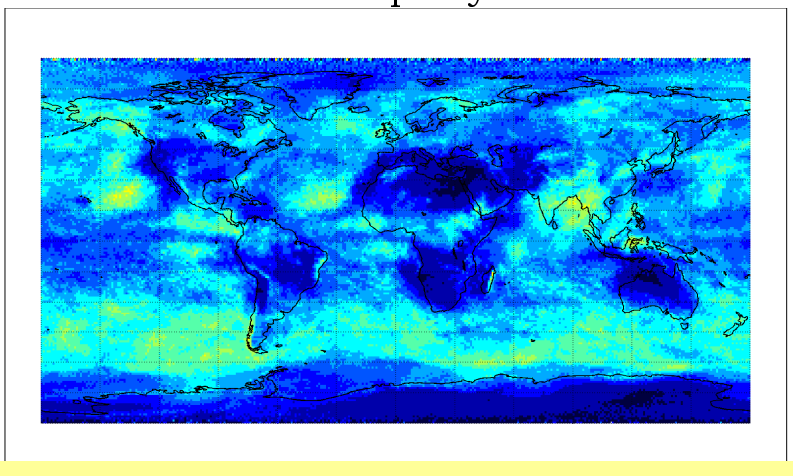
Direct model output Ne



Calculated Ne from proxy 3-9h forecast



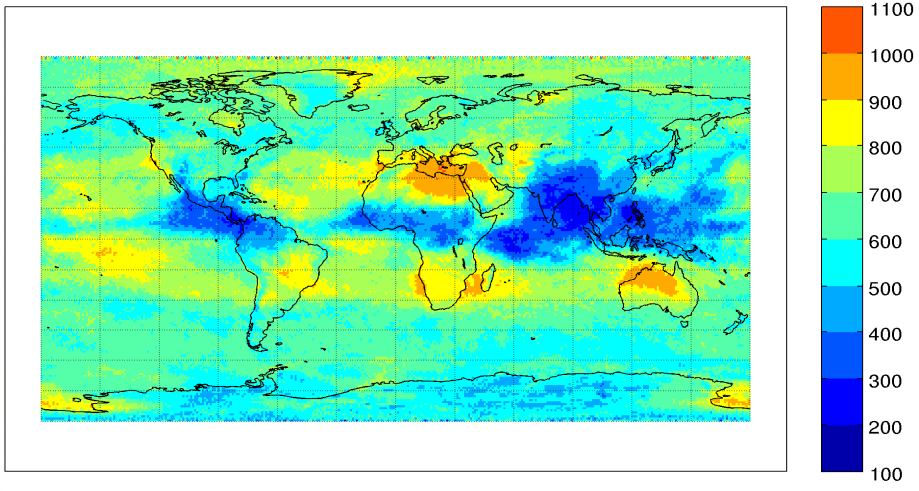
Calculated Ne from proxy 9-15h forecast



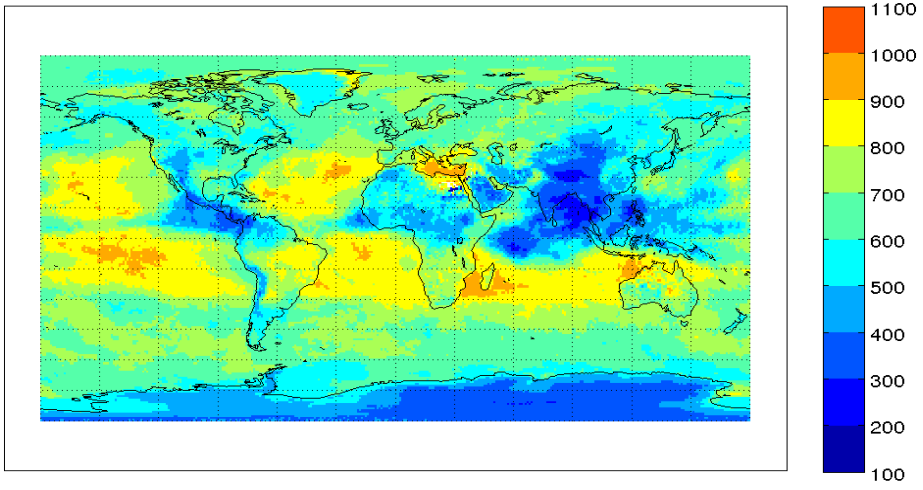
Good overall agreement between observed and calculated; superior mean amounts in model map

Cloud parameters comparison with MODIS

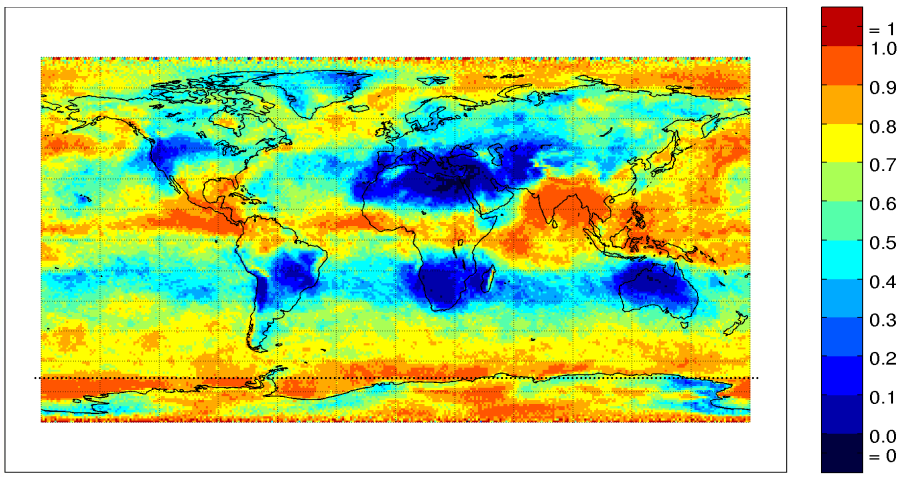
AIRS Observed CTP



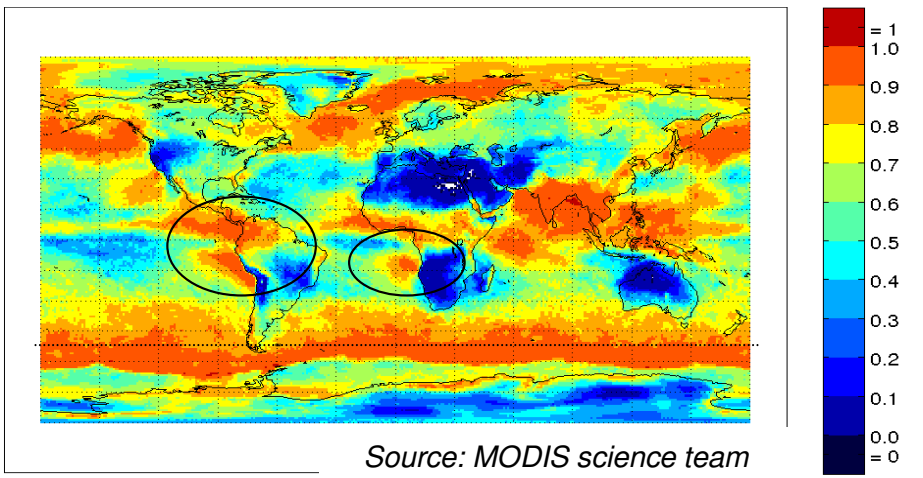
MODIS CTP



Model Cloud Fraction



MODIS Cloud Fraction



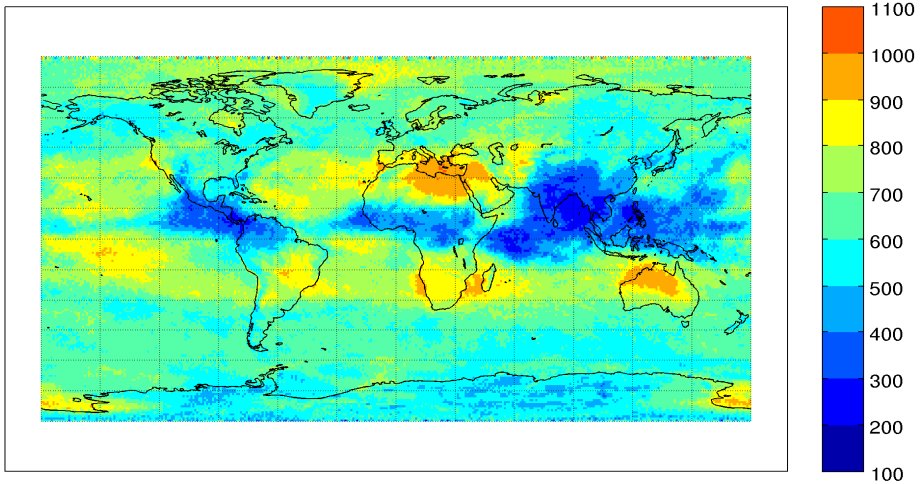
Source: MODIS science team

Good overall agreement between AIRS and independent MODIS parameters, except weak AIRS detection of stratocumulus clouds on western coasts of continents and different level of high cloud fraction pattern at N of Antarctica

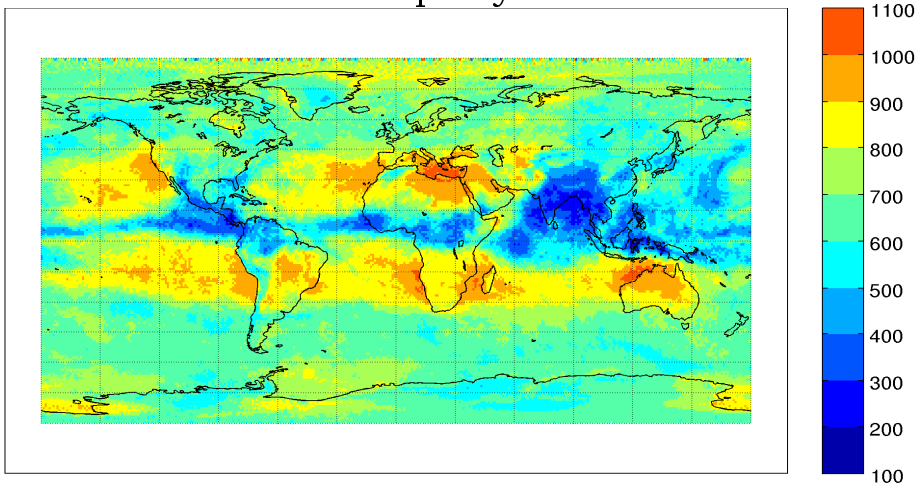
Validation results: monthly maps of cloud parameters

Cloud Top Pressure CTP (July 2008)

Observed CTP



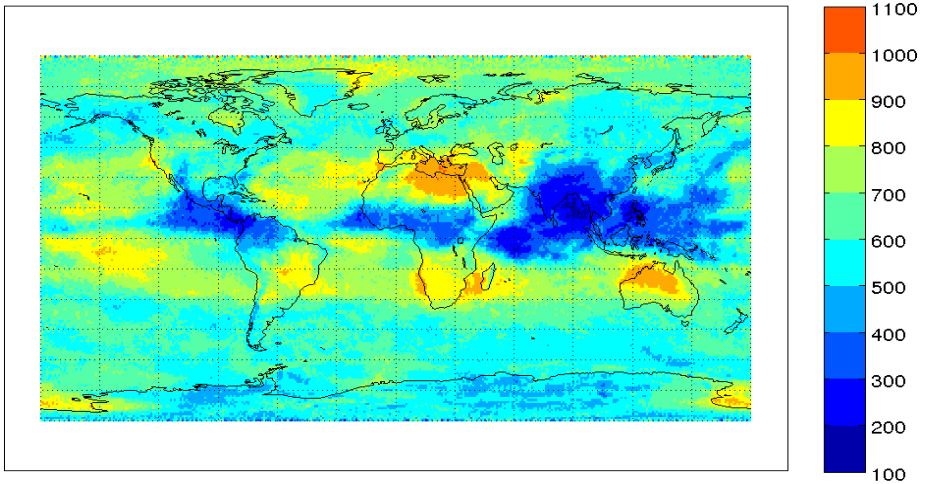
Calculated CTP from proxy 3-9h forecast



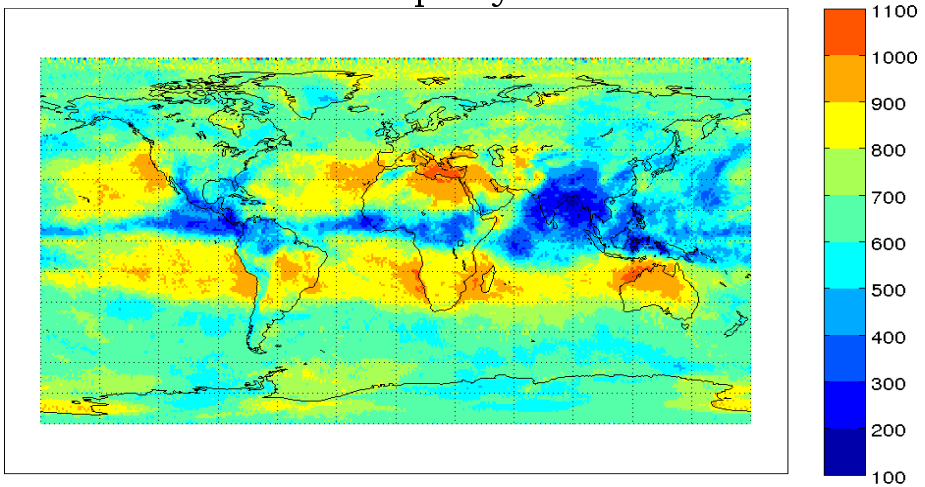
Validation results: monthly maps of cloud parameters

Cloud Top Pressure CTP after bias correction1 (July 2008)

Observed CTP



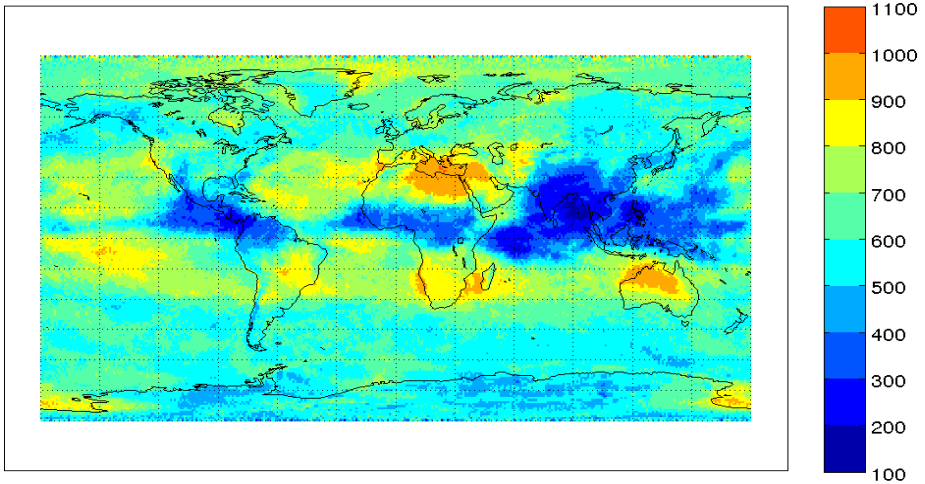
Calculated CTP from proxy 3-9h forecast



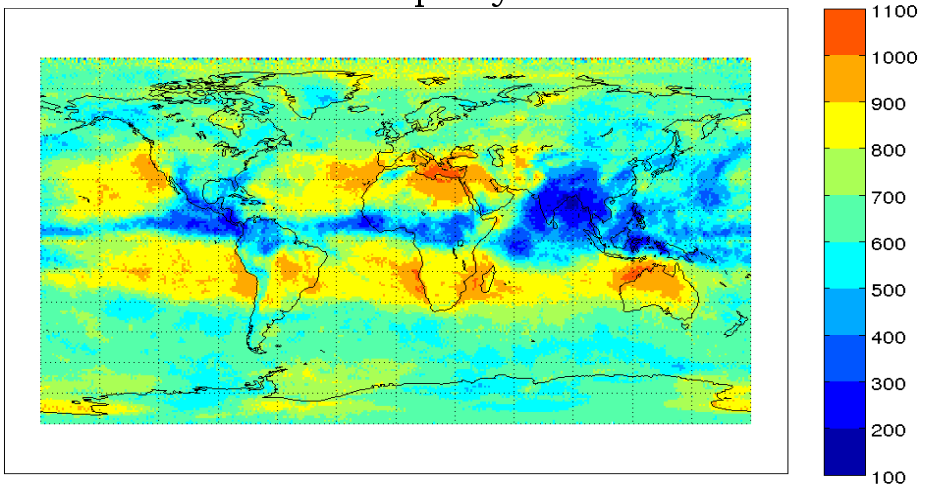
Validation results: monthly maps of cloud parameters

Cloud Top Pressure CTP after bias correction2 (July 2008)

Observed CTP



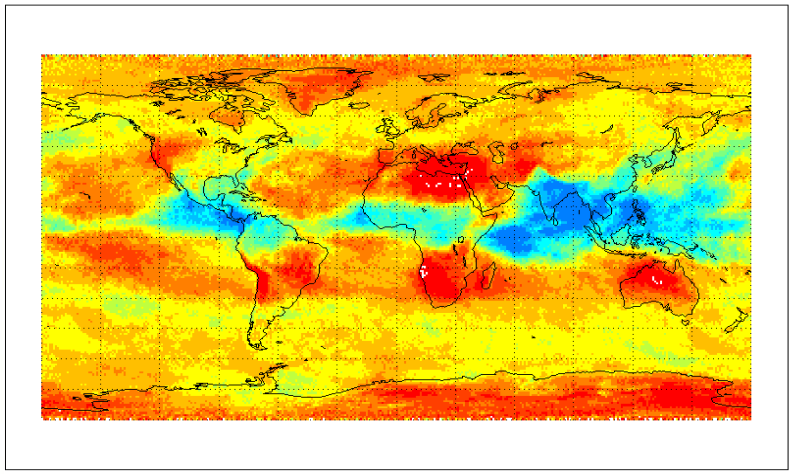
Calculated CTP from proxy 3-9h forecast



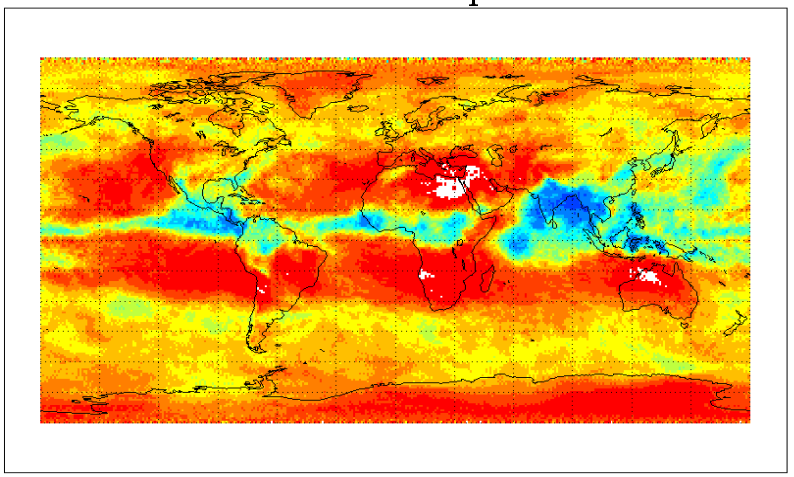
Validation results: monthly maps of cloud parameters

Cloud Top Height CTH (July 2008)

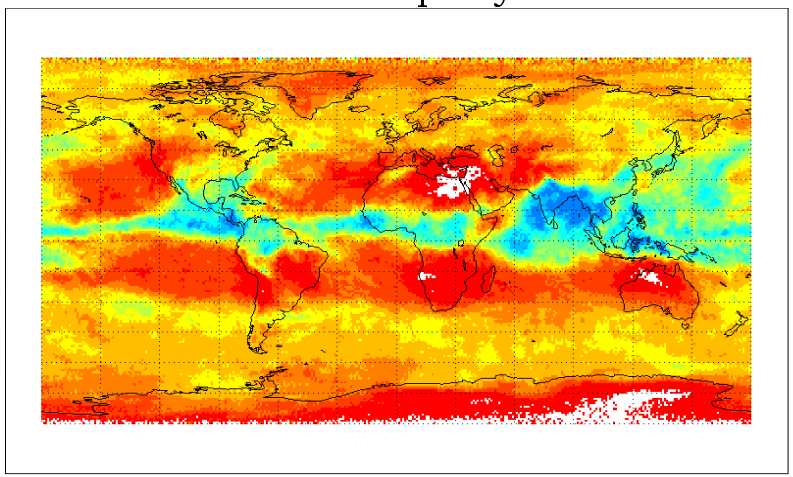
Observed CTH



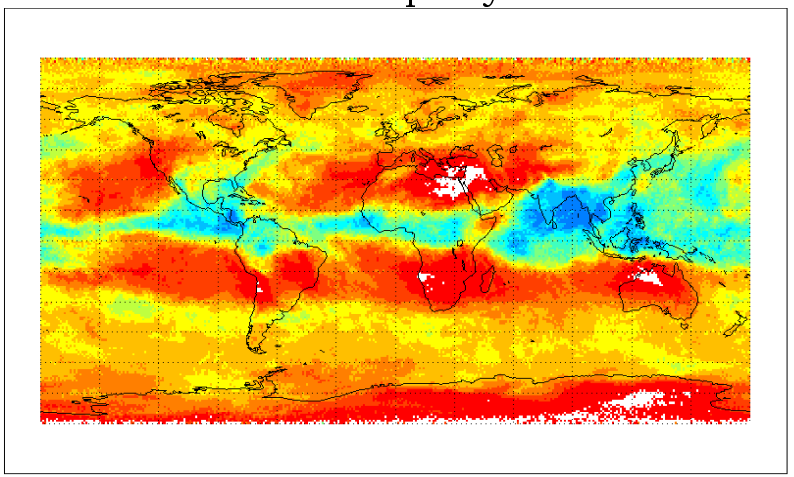
Direct model output CTH



Calculated CTH from proxy 3-9h forecast



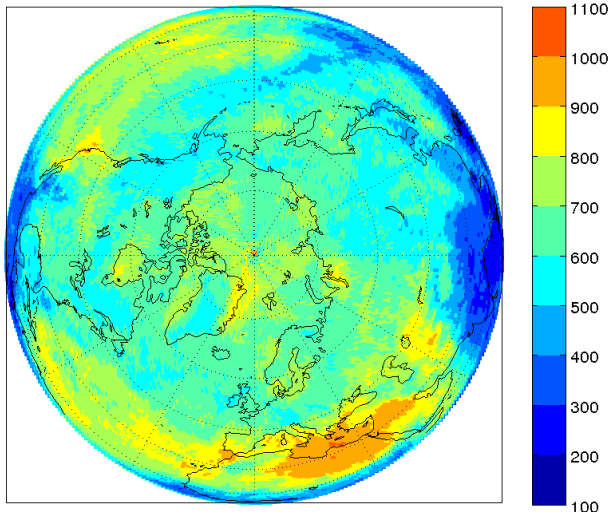
Calculated CTH from proxy 9-15h forecast



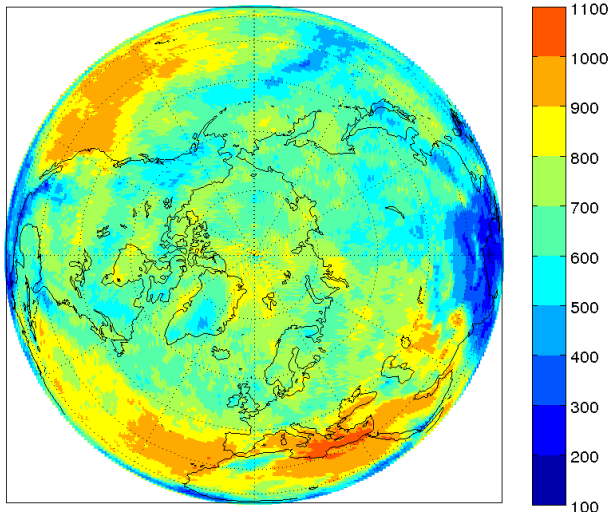
Focus on Arctic area: monthly maps of cloud parameters

Cloud Top Pressure CTP (July 2008)

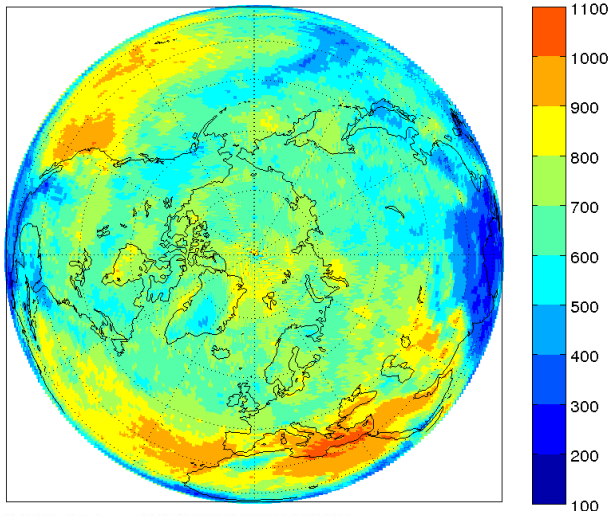
Observed CTP



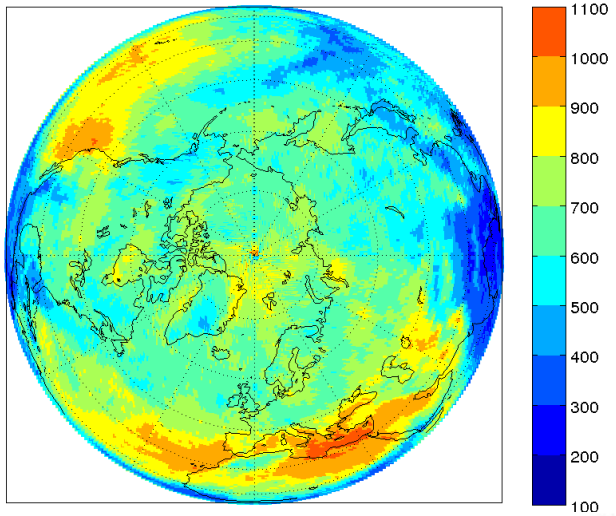
Direct model output CTP



Calculated CTP from proxy 3-9h forecast



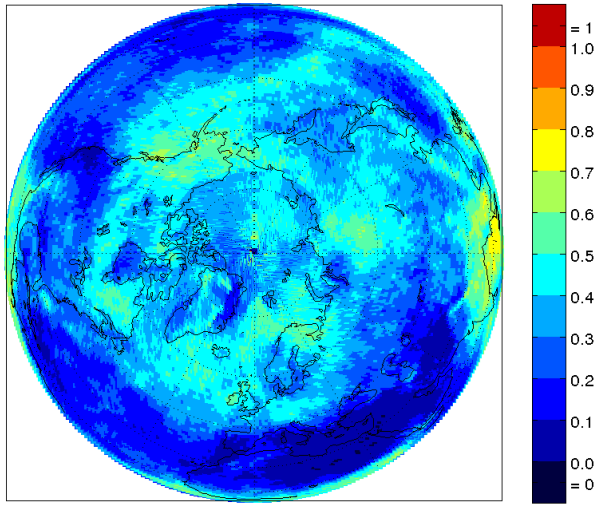
Calculated CTP from proxy 9-15h forecast



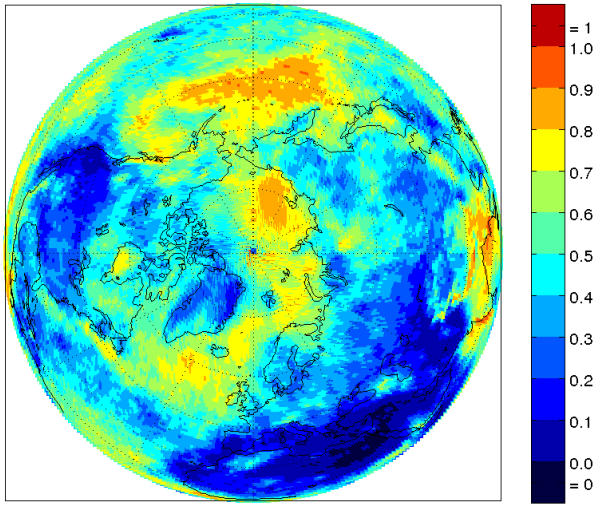
Focus on Arctic area: monthly maps of cloud parameters

Cloud Amount Ne (July 2008)

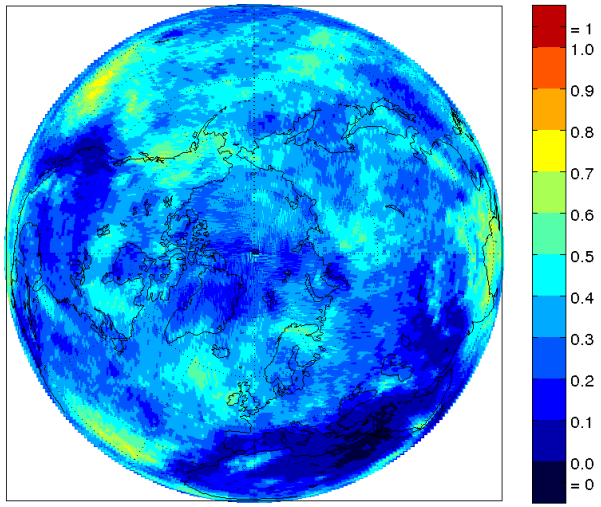
Observed Ne



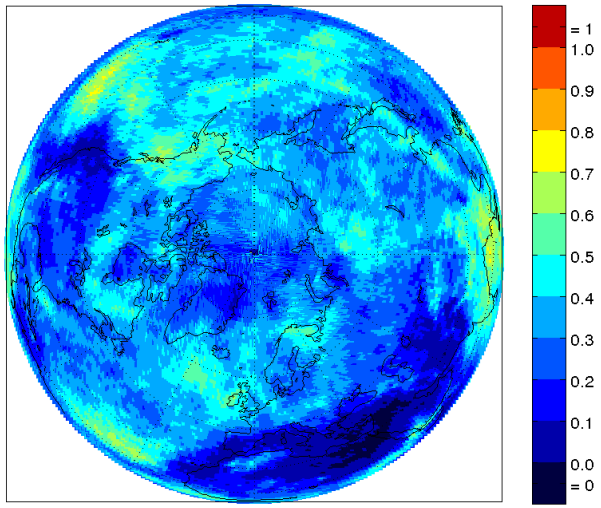
Direct model output Ne



Calculated Ne from proxy 3-9h forecast

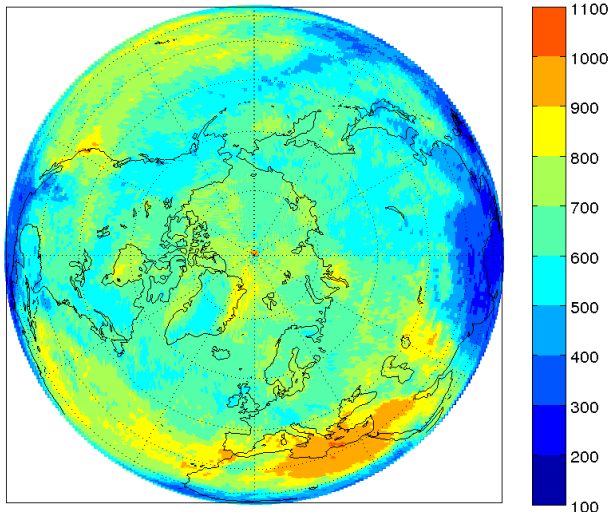


Calculated Ne from proxy 9-15h forecast

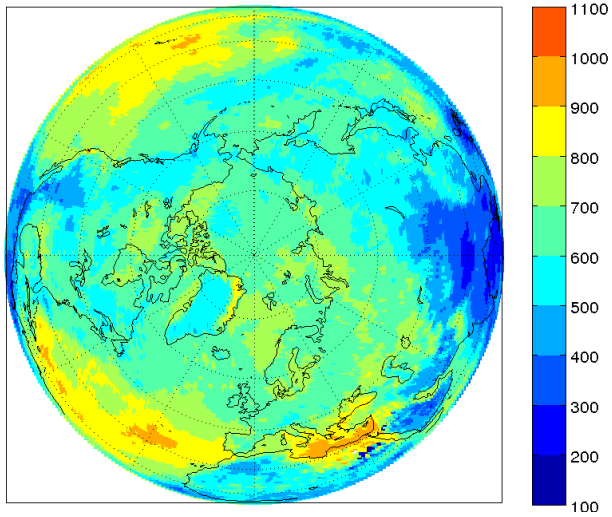


Focus on Arctic area:
Cloud parameters comparison with MODIS

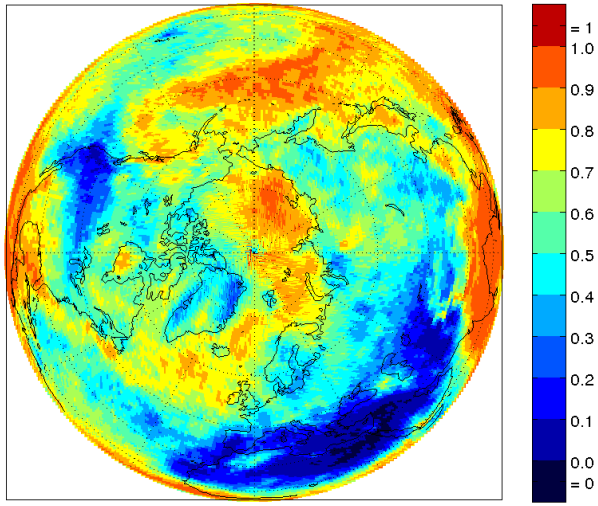
AIRS Observed CTP



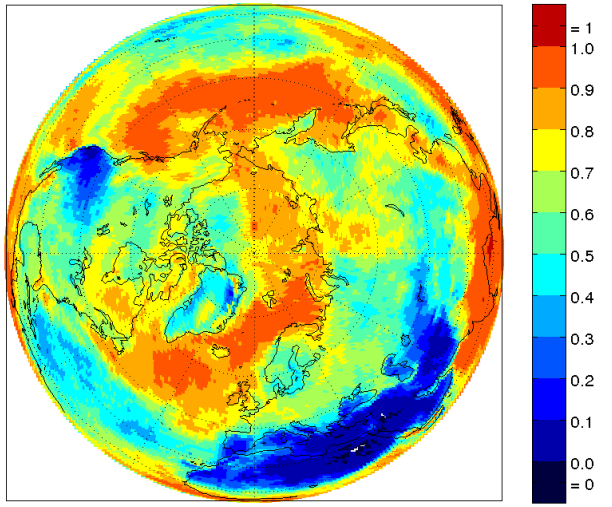
MODIS CTP



Model Cloud Fraction



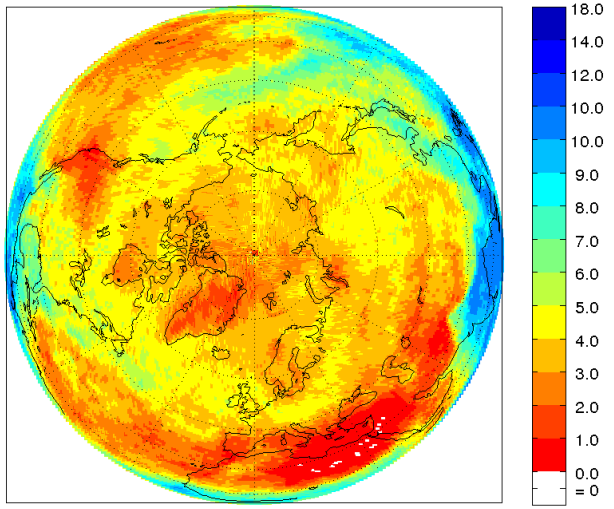
MODIS Cloud Fraction



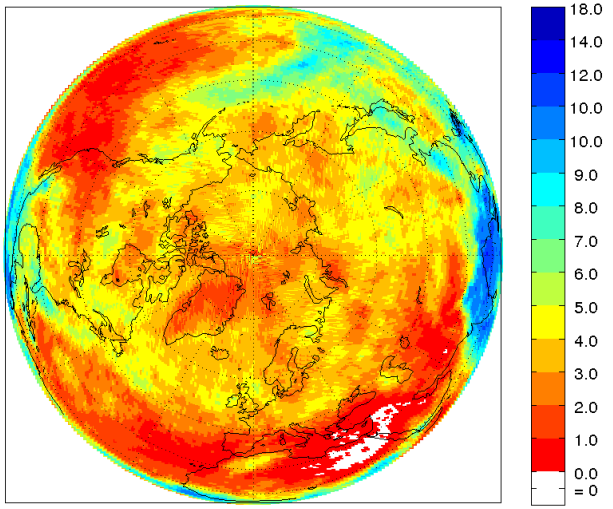
Focus on Arctic area: monthly maps of cloud parameters

Cloud Top Height CTH (July 2008)

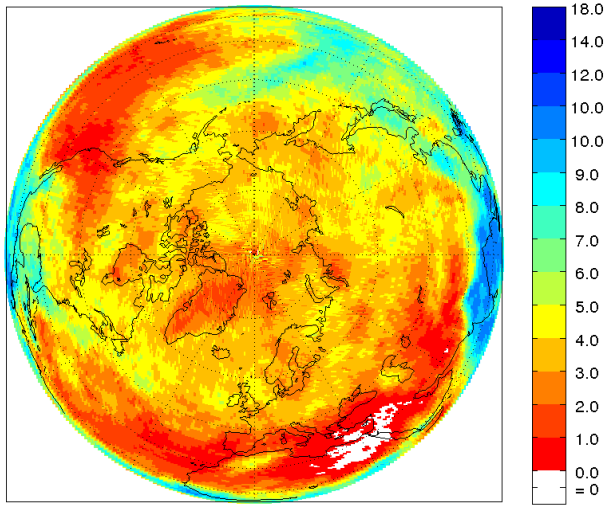
Observed CTH



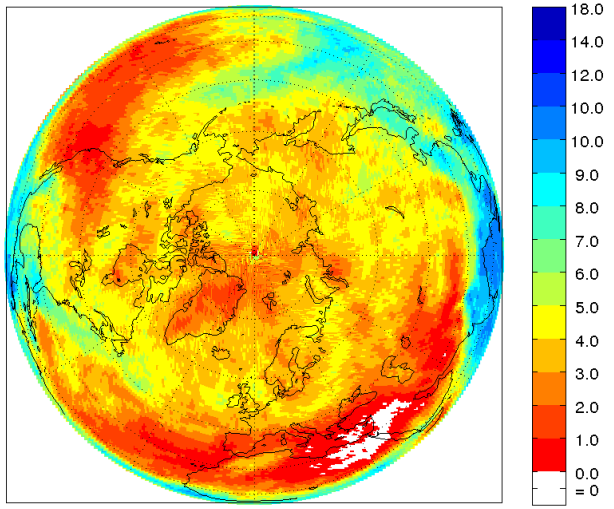
Direct model output CTH



Calculated CTH from proxy 3-9h forecast



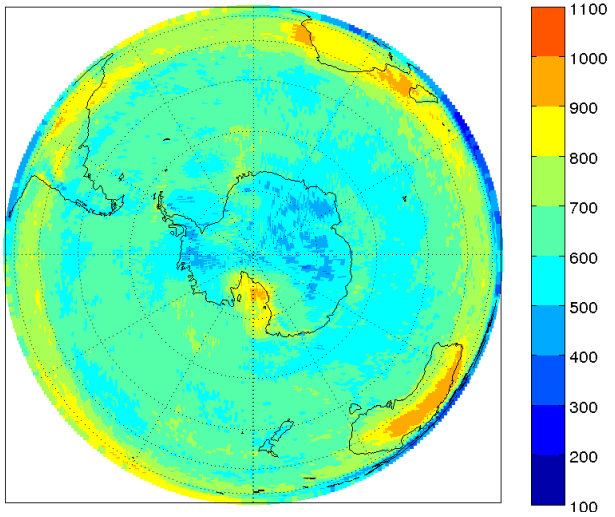
Calculated CTH from proxy 9-15h forecast



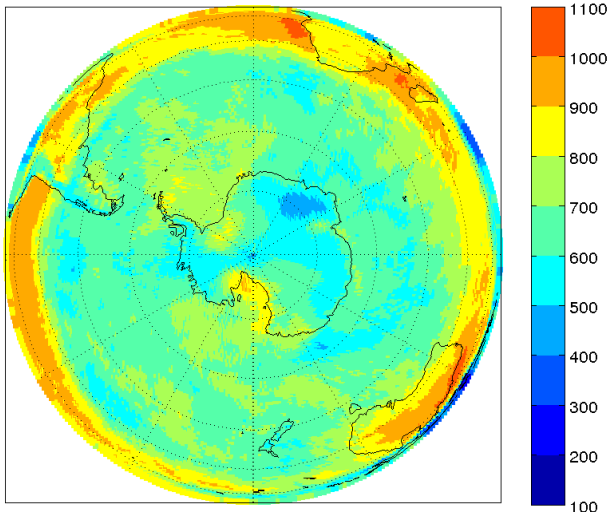
Focus on Antarctic area: monthly maps of cloud parameters

Cloud Top Pressure CTP (July 2008)

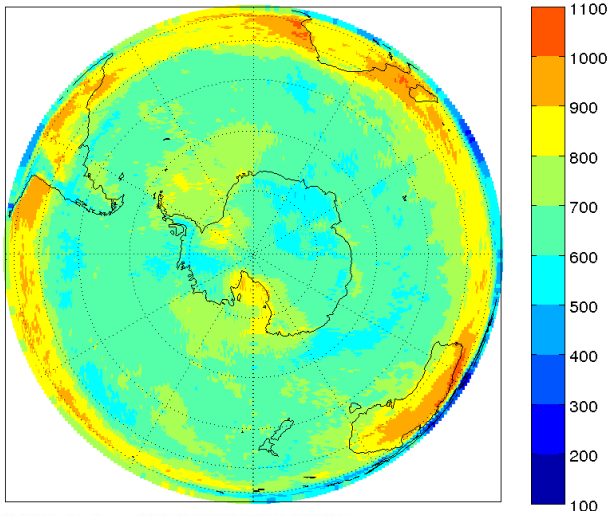
Observed CTP



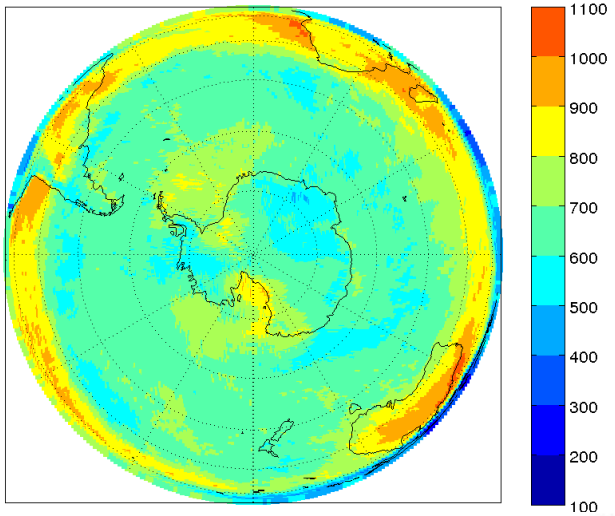
Direct model output CTP



Calculated CTP from proxy 3-9h forecast



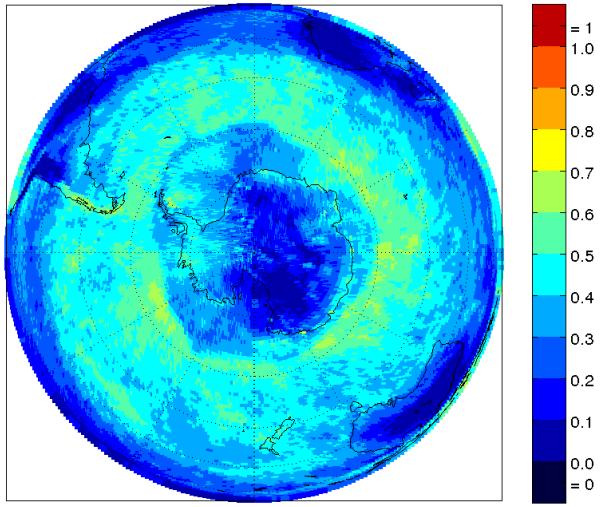
Calculated CTP from proxy 9-15h forecast



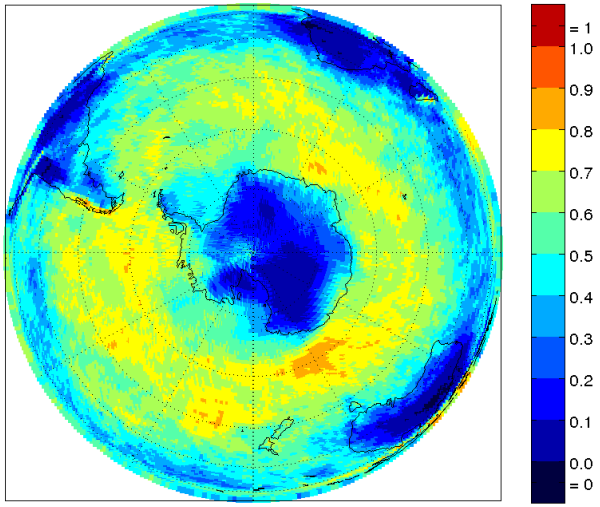
Focus on Antarctic area: monthly maps of cloud parameters

Cloud Amount Ne (July 2008)

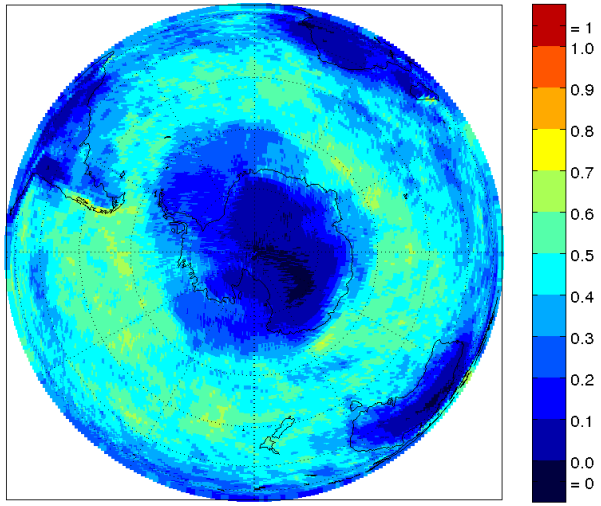
Observed Ne



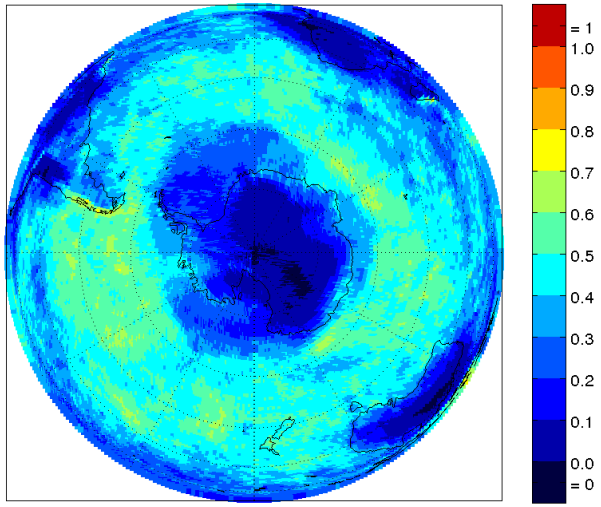
Direct model output Ne



Calculated Ne from proxy 3-9h forecast

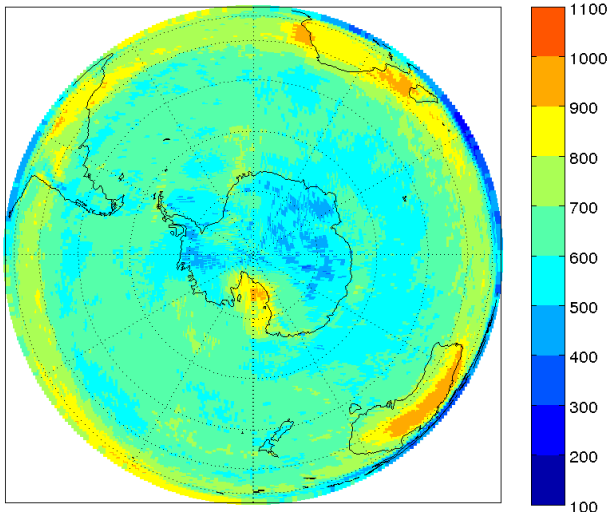


Calculated Ne from proxy 9-15h forecast

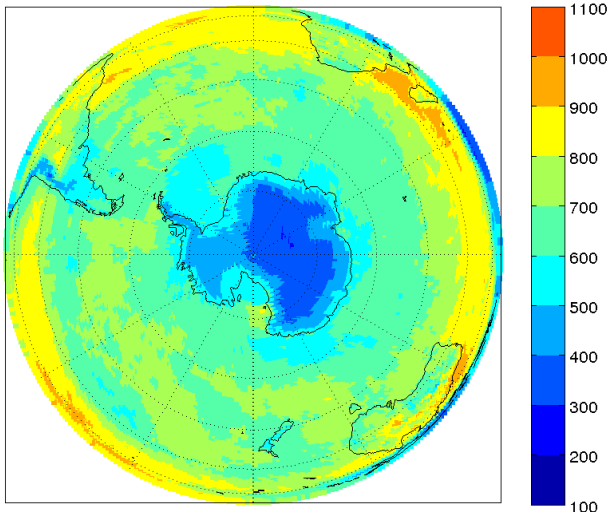


Focus on Antarctic area: Cloud parameters comparison with MODIS

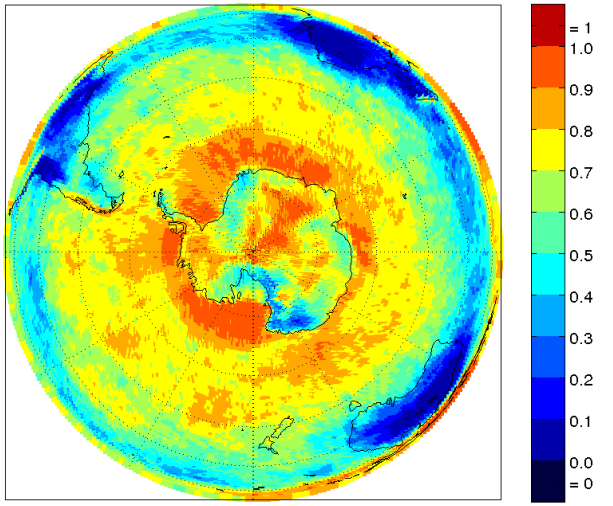
AIRS Observed CTP



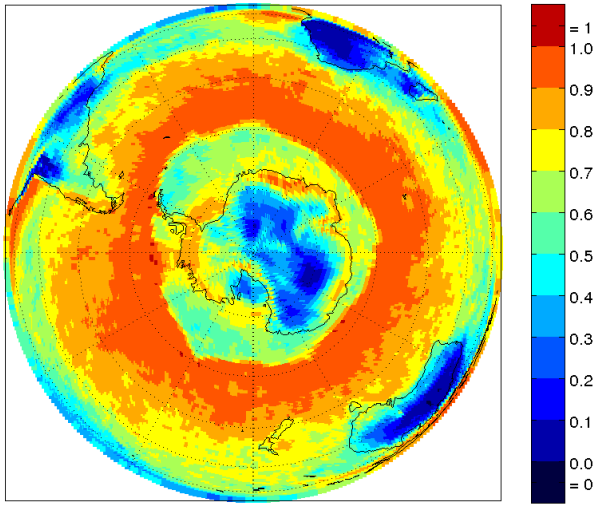
MODIS CTP



Model Cloud Fraction



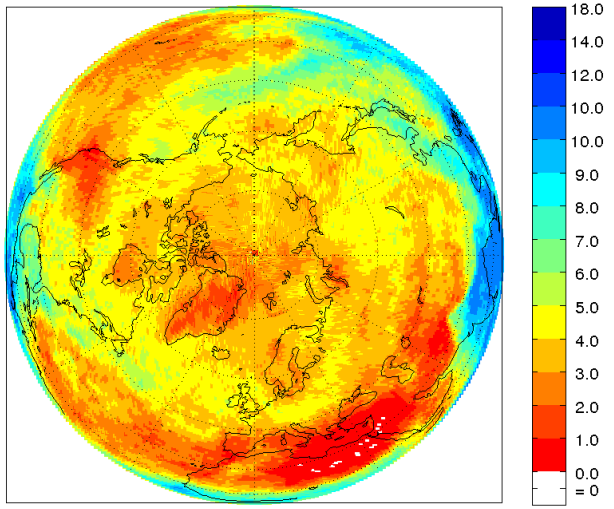
MODIS Cloud Fraction



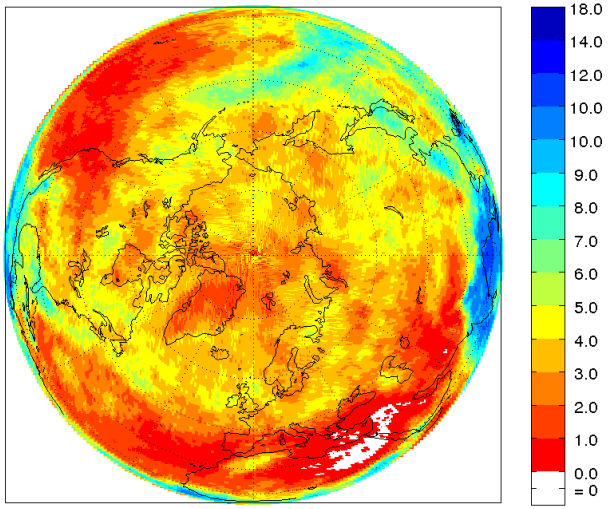
Focus on Antarctic area: monthly maps of cloud parameters

Cloud Top Height CTH (July 2008)

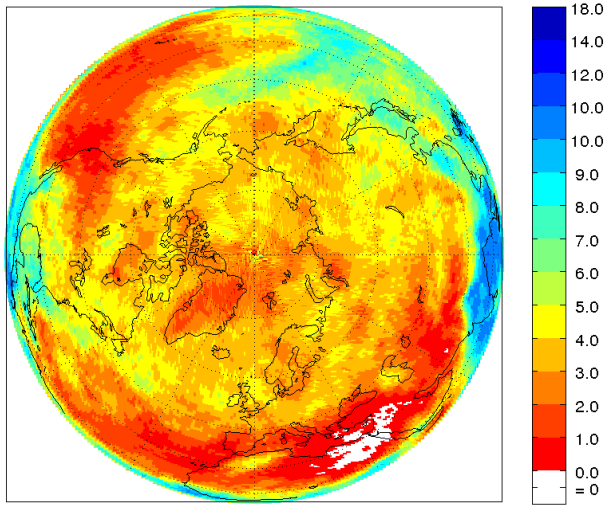
Observed CTH



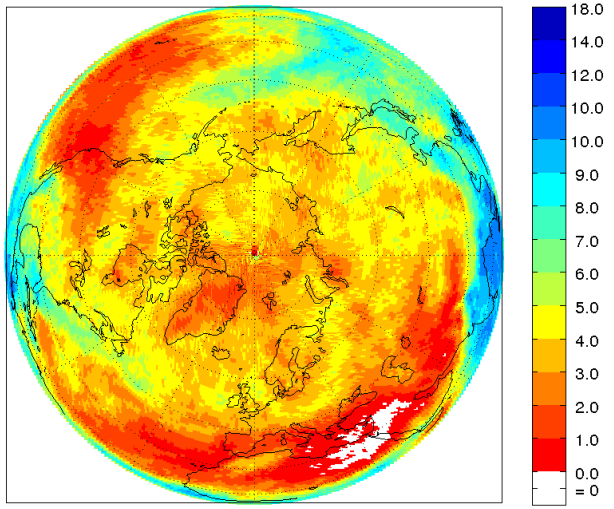
Direct model output CTH



Calculated CTH from proxy 3-9h forecast



Calculated CTH from proxy 9-15h forecast



Conclusion

- Using model output combined with calculated cloudy radiances allows to validate cloud parameter retrieval methodology for climate studies (notably minimize systematic retrieval biases on height)
- Retrieved parameters from both observed and simulated radiances remarkably similar. Cloud tops from model output slightly higher. However results sensitive to threshold $\boldsymbol{\tau_{cloud}}$
- CO_2-slicing revision confirms it is best to limit range to 13.1-14.2 μm, use independent pairs and retain median. This impacts on radiance quality control.
- Proposed model definition of cloud top corresponds to physical height inferred from lidar CALIPSO data.
- Height bias increases with height to reach ~2 km at 16 km. This can be accounted for.
- Model validation tool developed based on CO_2-slicing applied to both real and proxy data provides useful information on model vertical cloud distribution deficiencies.
- Monthly height and cloud fraction distributions from AIRS compare well with MODIS ones.

Prospective

- Develop validation statistics for cloudy radiance spectra
- Validation of AIRS-derived cloud parameters with independent data, in particular for polar winter cases
- Assimilation tests with revised quality control
- Collaboration to IPY research on ice cloud parameterization
- Extend application to IASI, using available sub-grid information from AVHRR allowing to distinguish single layer clouds (where CO_2 - slicing works best) from multilayered clouds (where cloud tops are seen too low)
- 4 CO_2 - slicing channels close to MODIS configuration will be onboard the future mission PCW, so applicable methodology with a higher resolution (2km IR)
- Publication on improved methodology suitable for both real time and climate applications. Other publication specific to polar applications.