Evaluation of Passive Multilayer Cloud Detection Using Preliminary CloudSat & CALIPSO Cloud Profiles

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Introduction

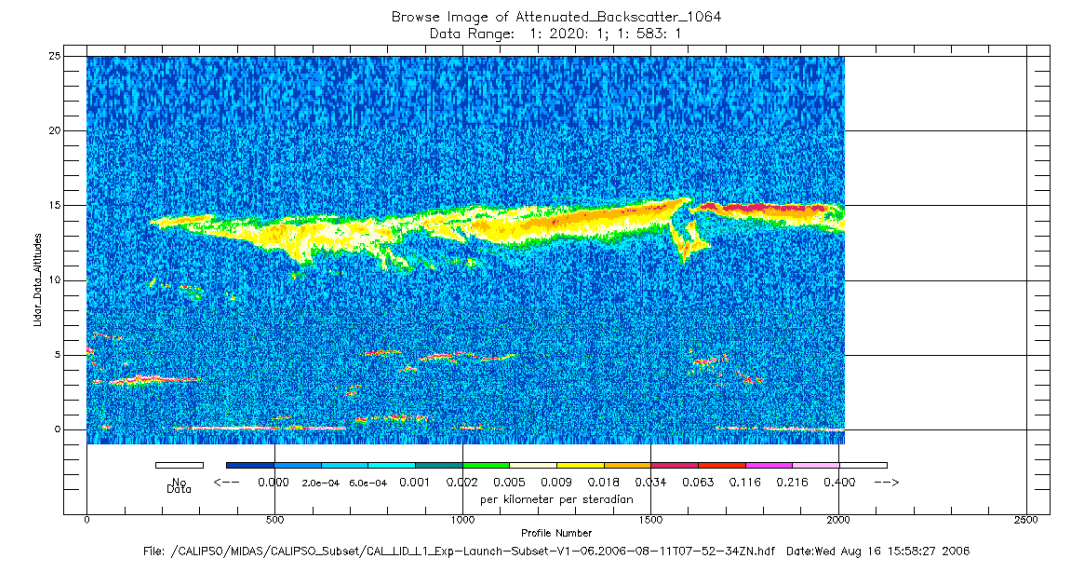
- New passive algorithms available to detect multilayered clouds
- Difficult to test with earlier datasets
- CALIPSO & CloudSat provide unprecedented multilayer detectability on a global basis

Objective

- Begin process of validating & refining these new methods

- Define multilayered (ML) clouds with CALIPSO & determine frequency of positive & negative matches for each algorithm

CALIPSO Lidar Vertical Feature Mask



- **Detects & defines atmospheric features: subsurface, surface, cloud, aerosol, stratospheric feature**

- **Clouds: determines phase of each layer, can penetrate through optical depth 2-3 classifies according to cloud type**

- **Study uses the first release cloud products**

CERES Multilayer Detection Methods

- **Applied to 1-km MODIS data**

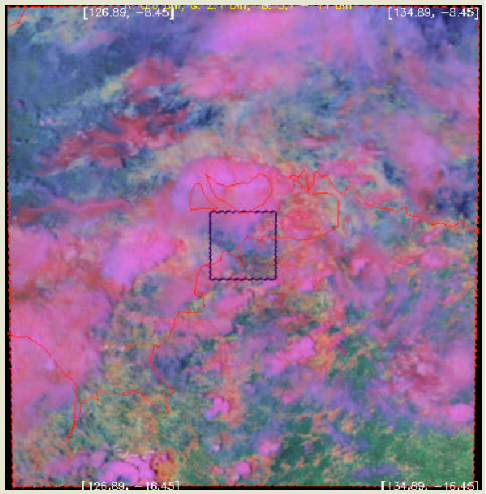
- **Edition 2: Single-layer (SL) only, VISST used to retrieve cloud phase, height, optical depth τ & particle size for each pixel**

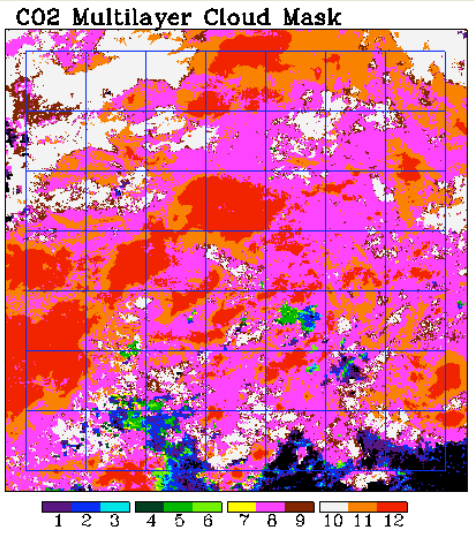
- **Edition 3 (2007): VISST + ML detection & retrieval of layer properties**

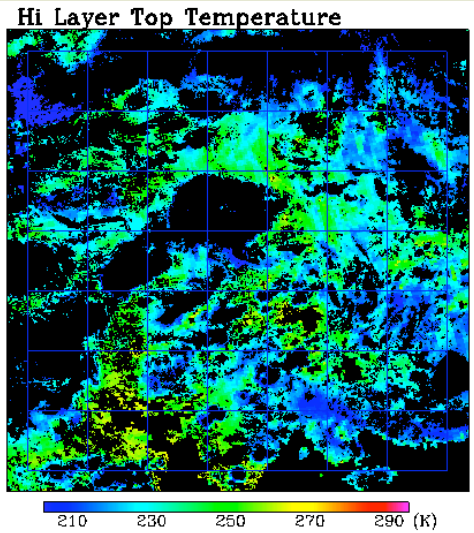
- **ML detection:**
  - **CO2-slicing method** (*Chang & Li*, 2005)
    compares SL emissivity to CO2 emissivity
    works only if $\tau_{upper} < 3$ & $\tau_{lower} > 3$

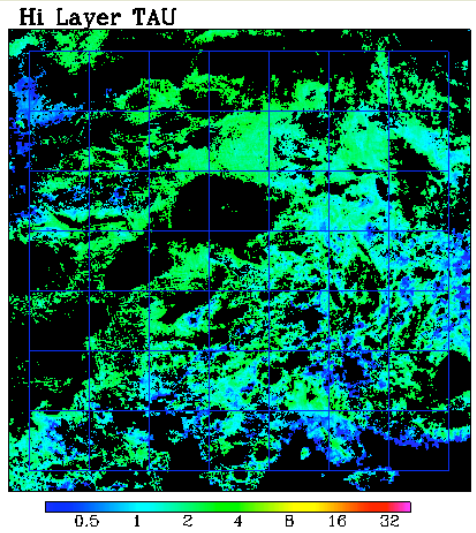
  - **BTD method** (*Pavolonis & Heidinger*, 2004)
    compares 11-12 μm brightness temperature difference to value expected for visible reflectance
    2 versions used: P&H reflectance and P&H w/τ
    works only if $\tau_{upper} < 3$ & $\tau_{lower} > 3$

Example of CO_2 detection results & retrieval
TWP-ICE, Aqua, January 21, 2006, 0455 UTC

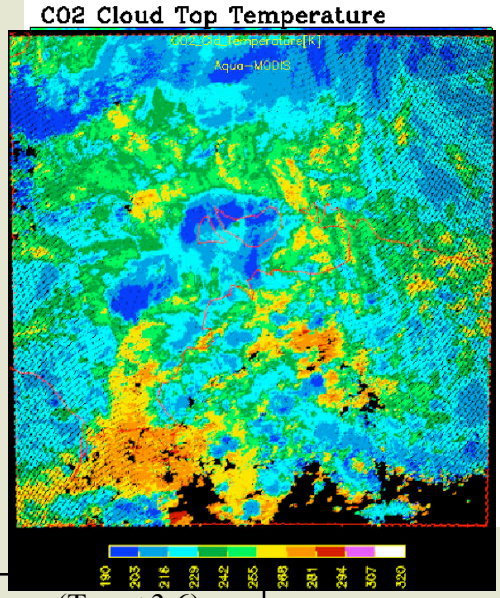


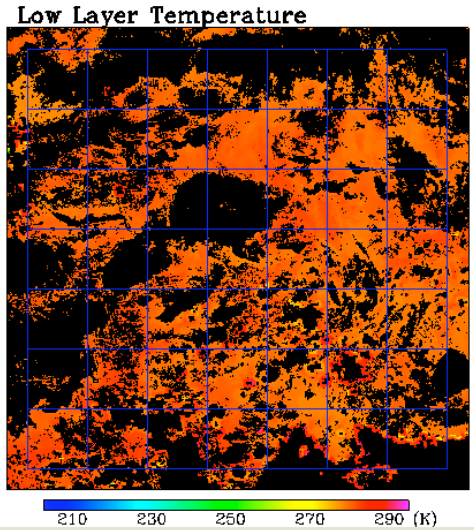


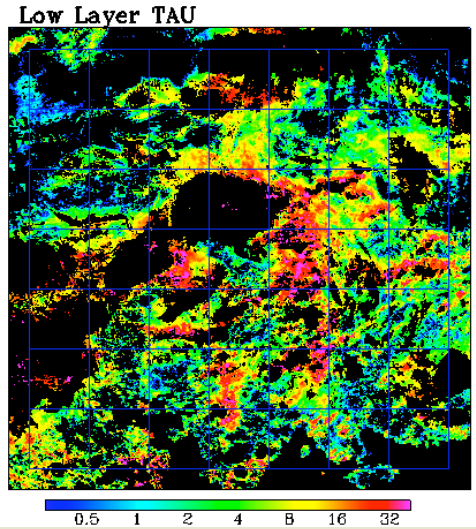




1: Single low (Tau < 3.6)
2: Single low (Tau = 3.6-23)
3: Single low (Tau > 23)





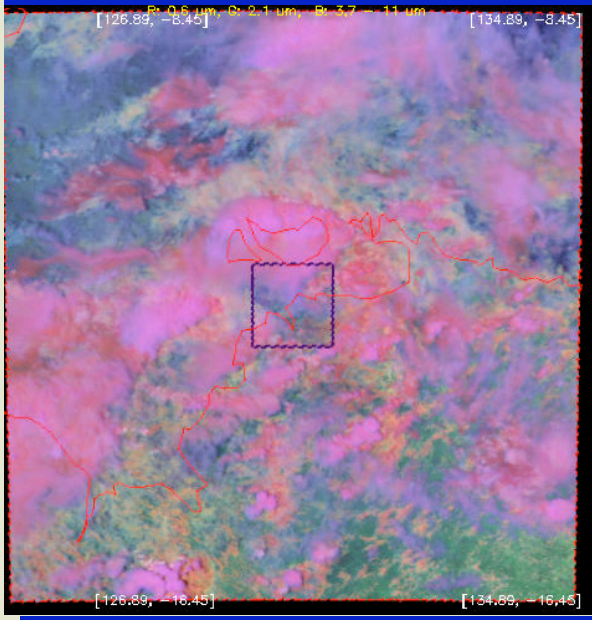


4: Single mid (Tau < 3.6)
5: Median (Tau = 3.6-23)
6: Thick mid (Tau > 23)

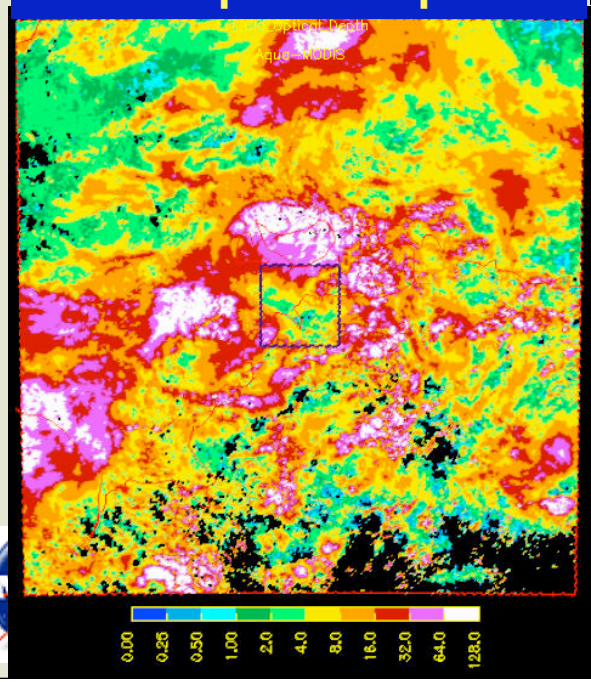
7: Multi mid
8: Multi high
9: Multi marginal

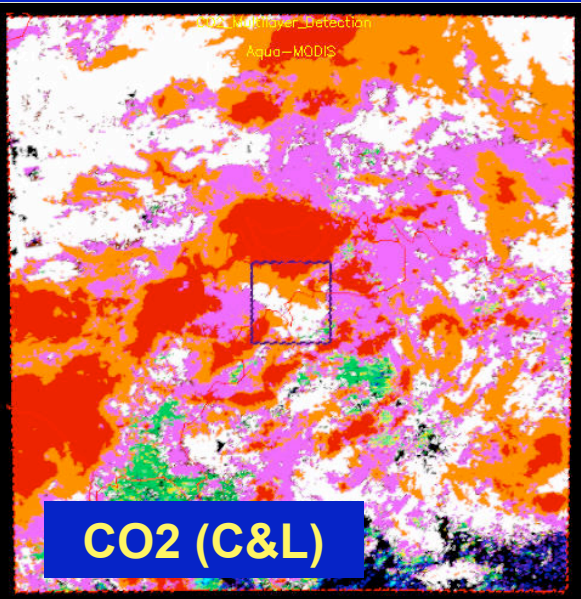
10: Single thin cirrus (Tau < 3.6)
11: Single cirrostratus (Tau =3.6-23)
12: Deep convective high (Tau > 23)

Multi-layer detection results & retrieval, Aqua, Jan. 21, 2006, 0455 UTC

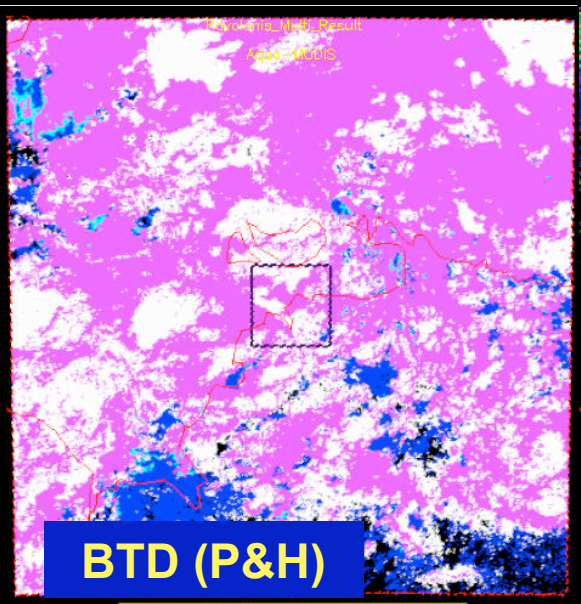


SL Optical Depth

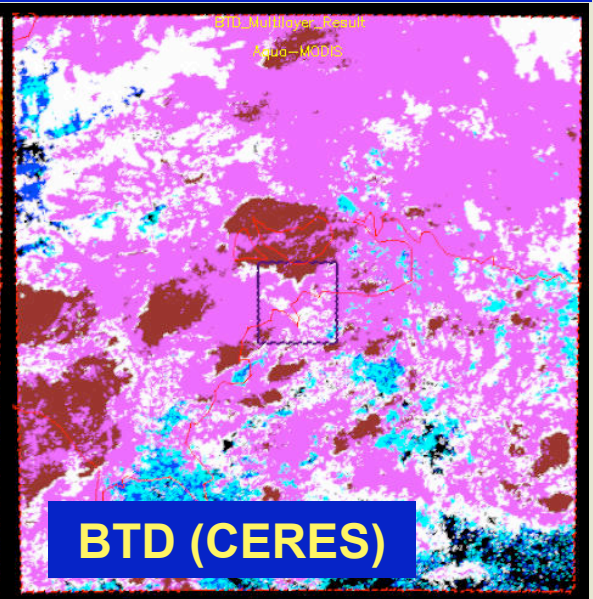




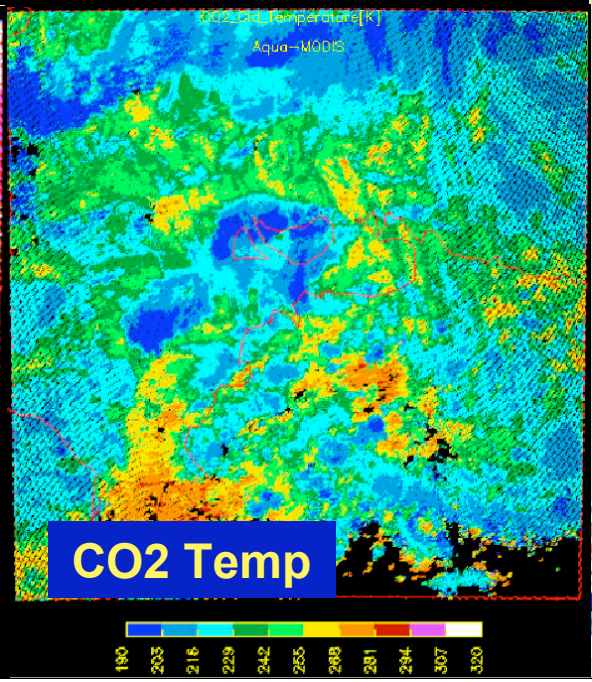
CO2 (C&L)



BTD (P&H)



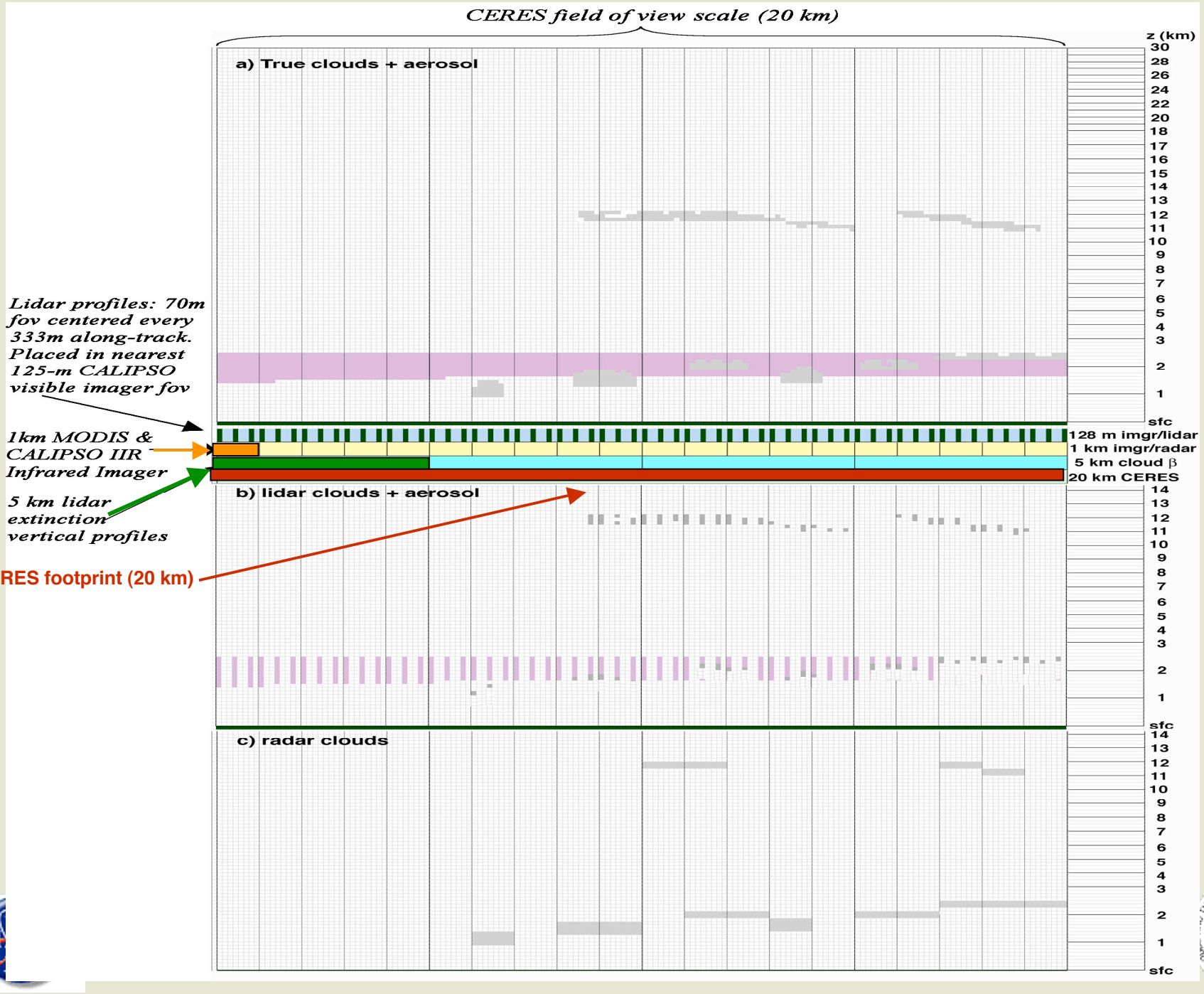
BTD (CERES)

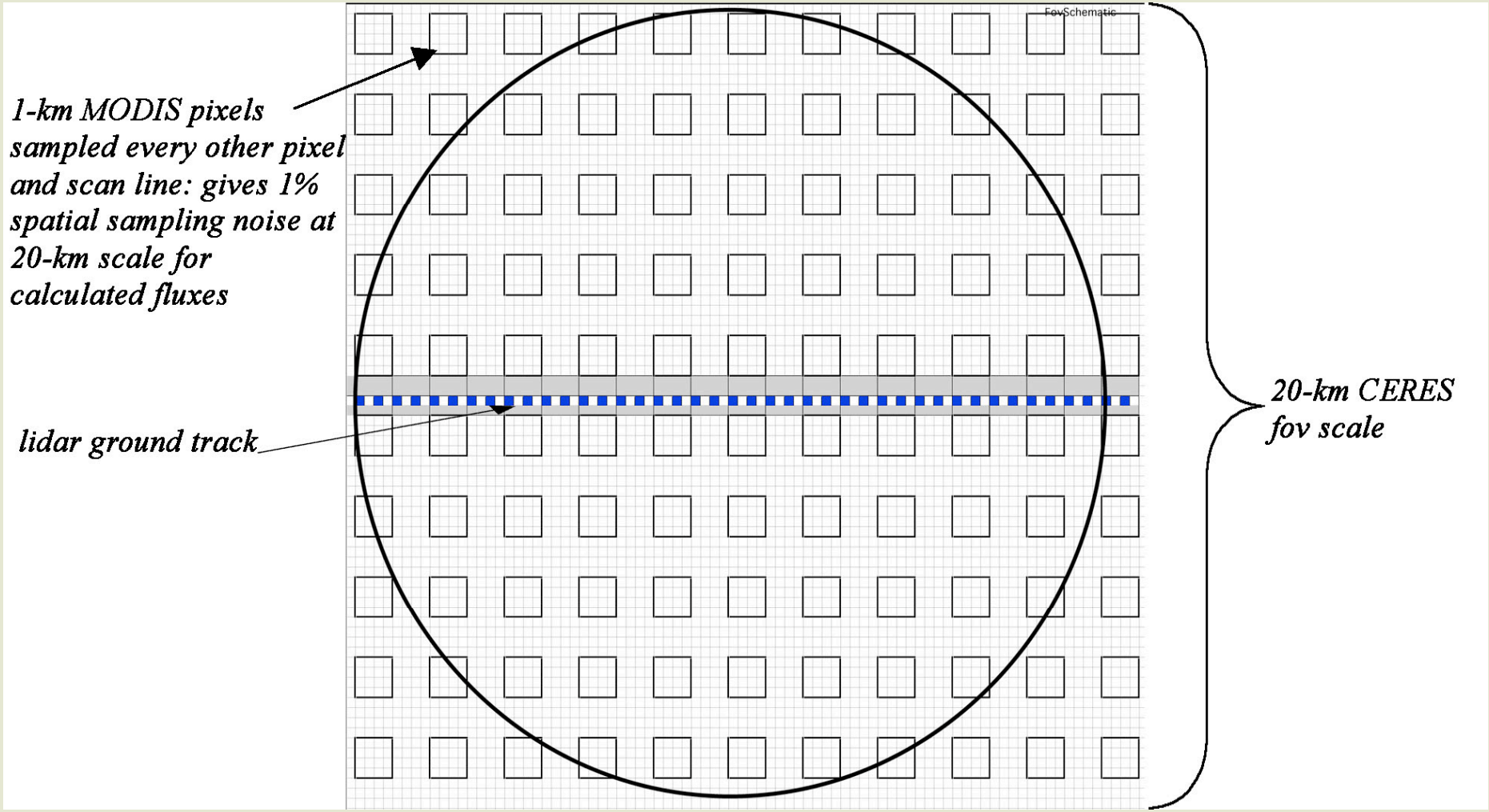


CO2 Temp

CALIPSO-MODIS Matching

- Account for differing fov sizes, time offset
- Select nearest CALIPSO fov to match MODIS 1-km pixel
- Perform similar matching with CloudSat
- Overlay the results

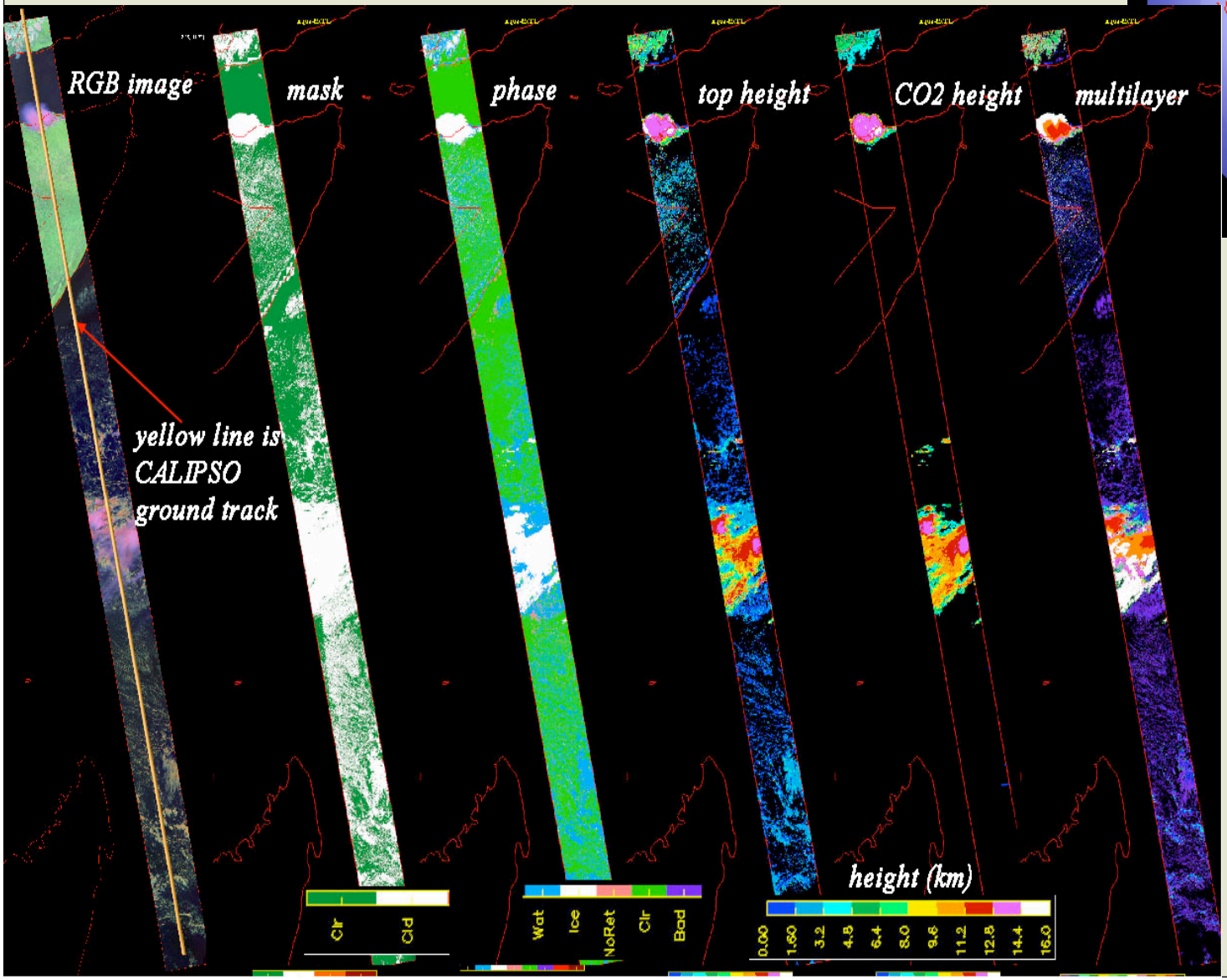

CERES field of view scale (20 km)
z (km)
a) True clouds + aerosol
Lidar profiles: 70m fov centered every 333m along-track. Placed in nearest 125-m CALIPSO visible imager fov
1km MODIS & CALIPSO IIR Infrared Imager
5 km lidar extinction vertical profiles
CERES footprint (20 km)
128 m imgr/lidar
1 km imgr/radar
5 km cloud β
20 km CERES
b) lidar clouds + aerosol
c) radar clouds
sfc

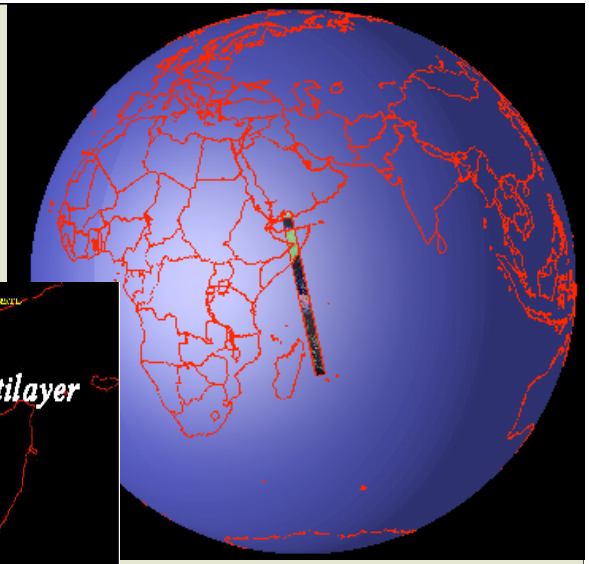


Schematic CERES FOV (circle) overlaid on sampled 1-km MODIS pixels (large squares, CPR track and IIR pixels (continuous gray), and CALIPSO lidar footprints (blue squares)

Example of typical CERES Cloud Retrieval Results.

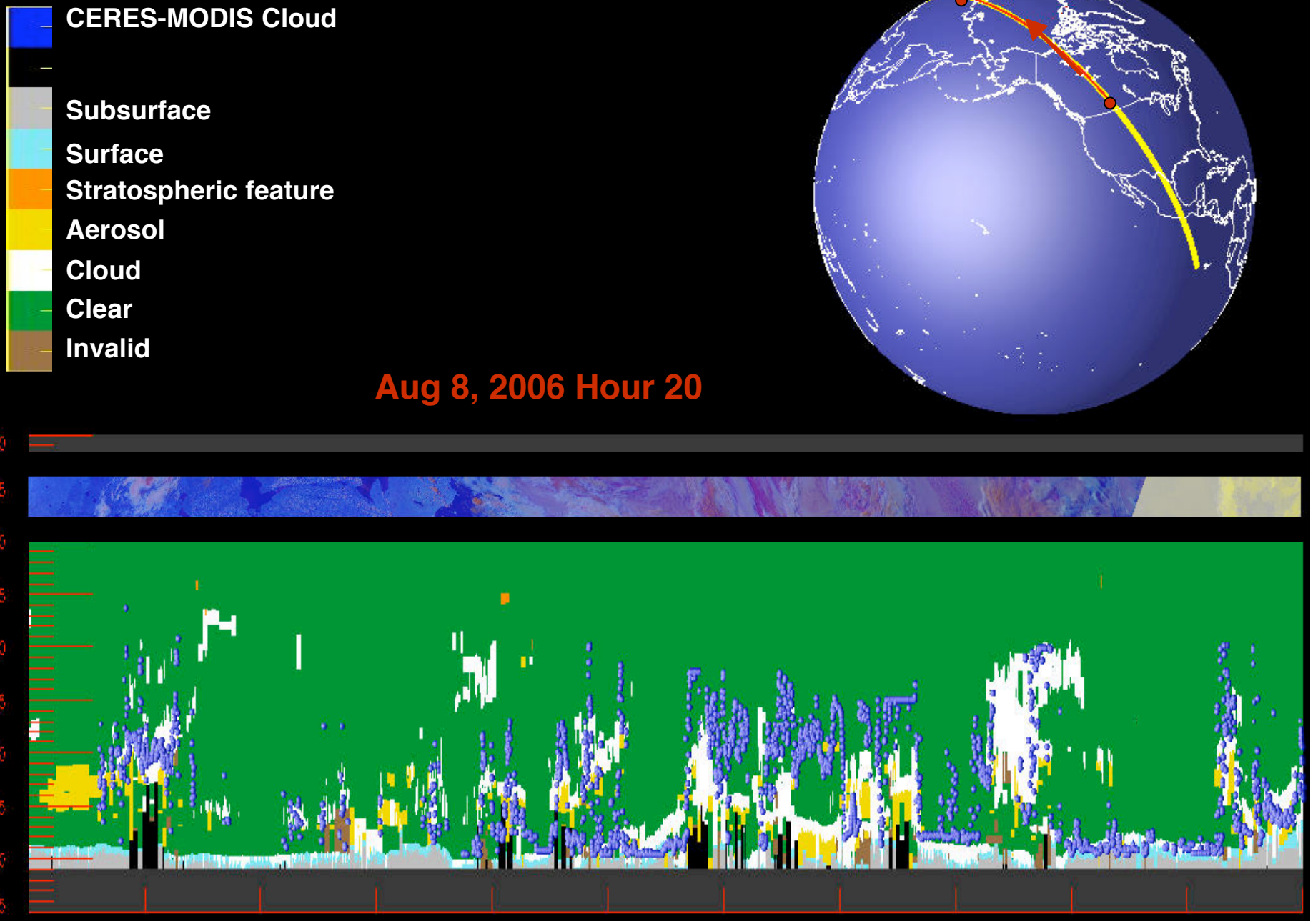
Full resolution MODIS 201 km / 22 channels subset
June 10, 2006, Hour 10





Strip of MODIS imagery and CERES-retrieved cloud products along the CALIPSO ground track over Horn of Africa (top) and western Indian Ocean, 10 June 2006. Multilayer clouds are indicated in yellow and magenta.

Merged product between CERES Cloud Top Height and Calipso Lidar Vertical Feature Mask



Merged product between CERES Cloud Phase and Calipso Lidar Cloud Phase

CERES-MODIS ice

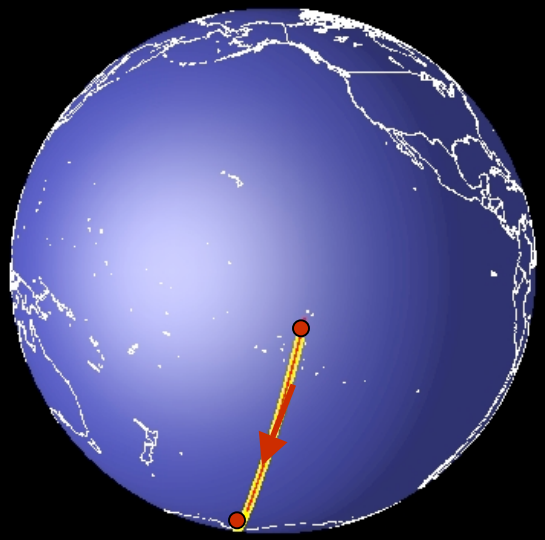
CERES-MODIS water

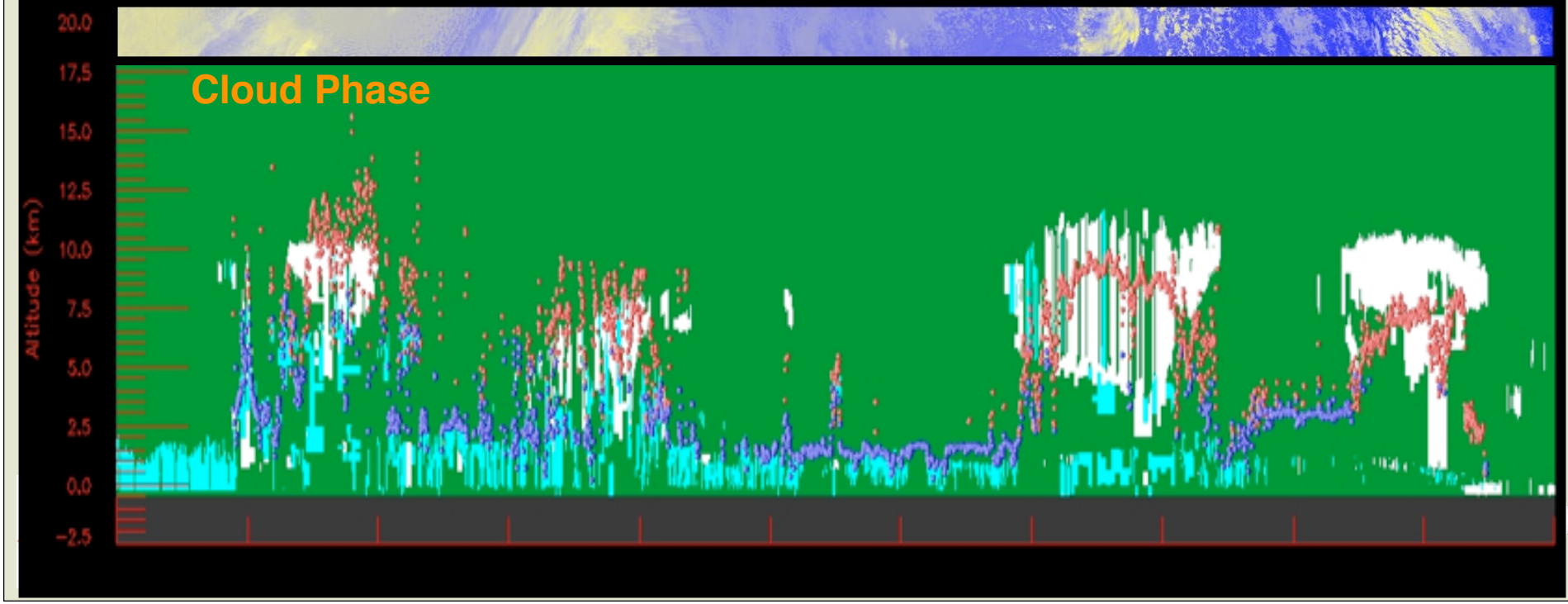
Calipso Mix

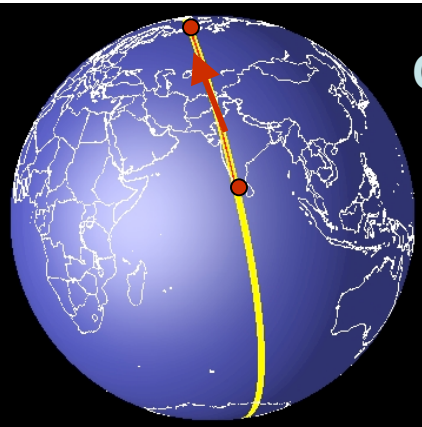
Calipso water

Calipso ice

Aug. 8, 2006, Hour 11







Comparison Between VISST and CO2 Cloud Retrievals, merged with Calipso Cloud Type

Aug. 8, 2006, Hour 8

CERES Ice
CERES Water
Deep Convective
Cirrus
Altostratus (opaque)
Altocumulus (transparent)
Low, broke cumulus
Transition stratocumulus
Low overcast (opaque)
Low overcast (transparent)

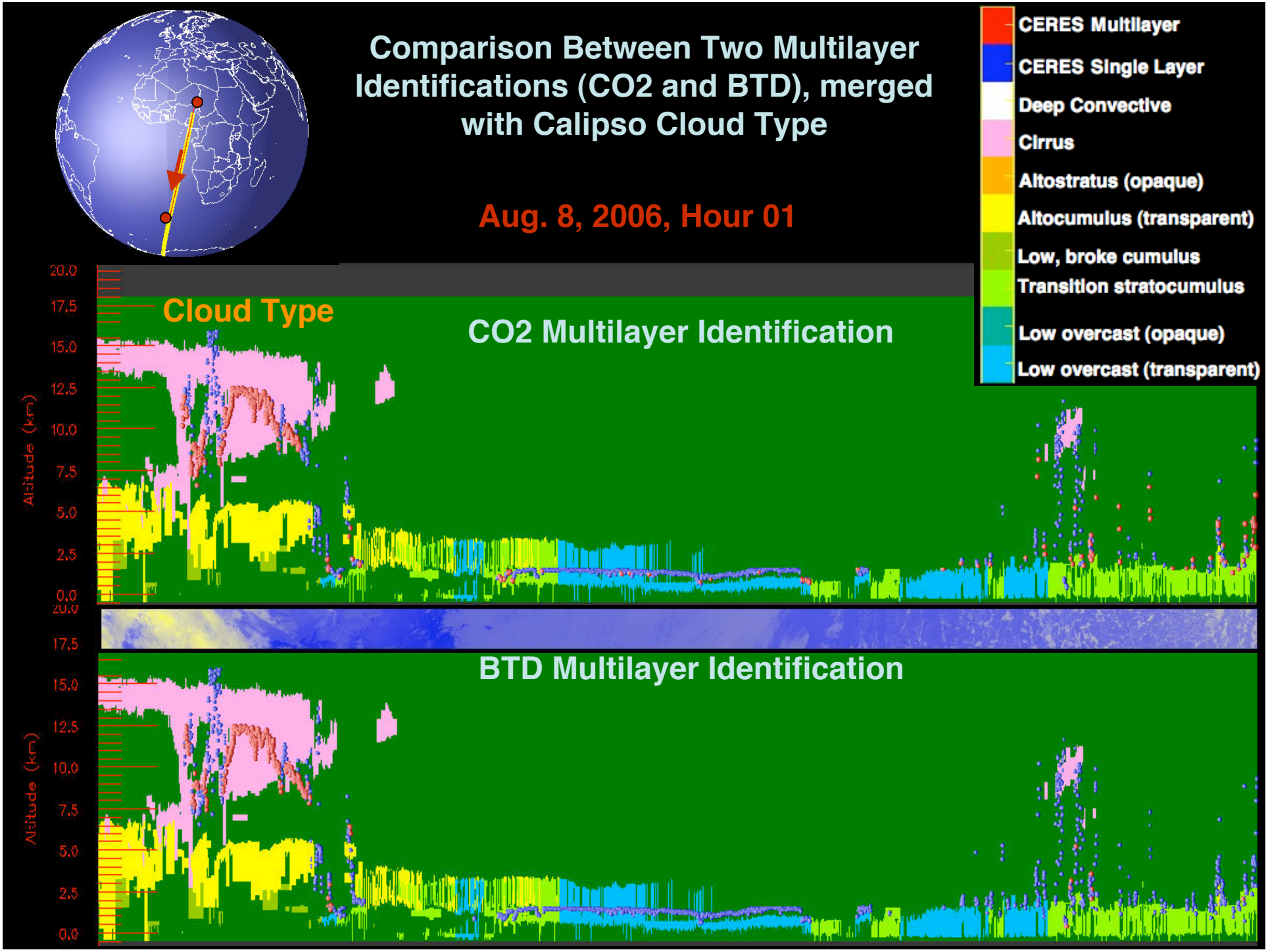
VISST /ISINT Cloud Top Height

Altitude (km)
15.0
12.5
10.0
7.5
5.0
2.5
0.0
-2.5

Cloud Type

CO2 Slicing Cloud Height

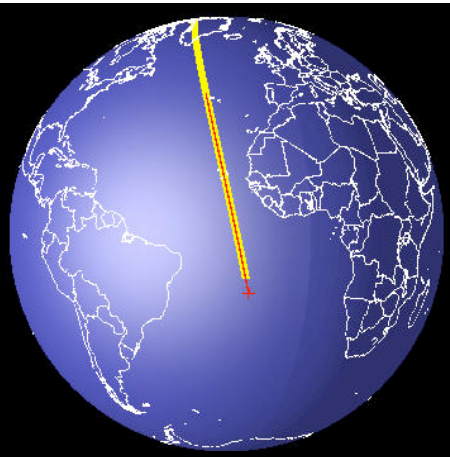
Altitude (km)
15.0
12.5
10.0
7.5
5.0
2.5
0.0
-2.5

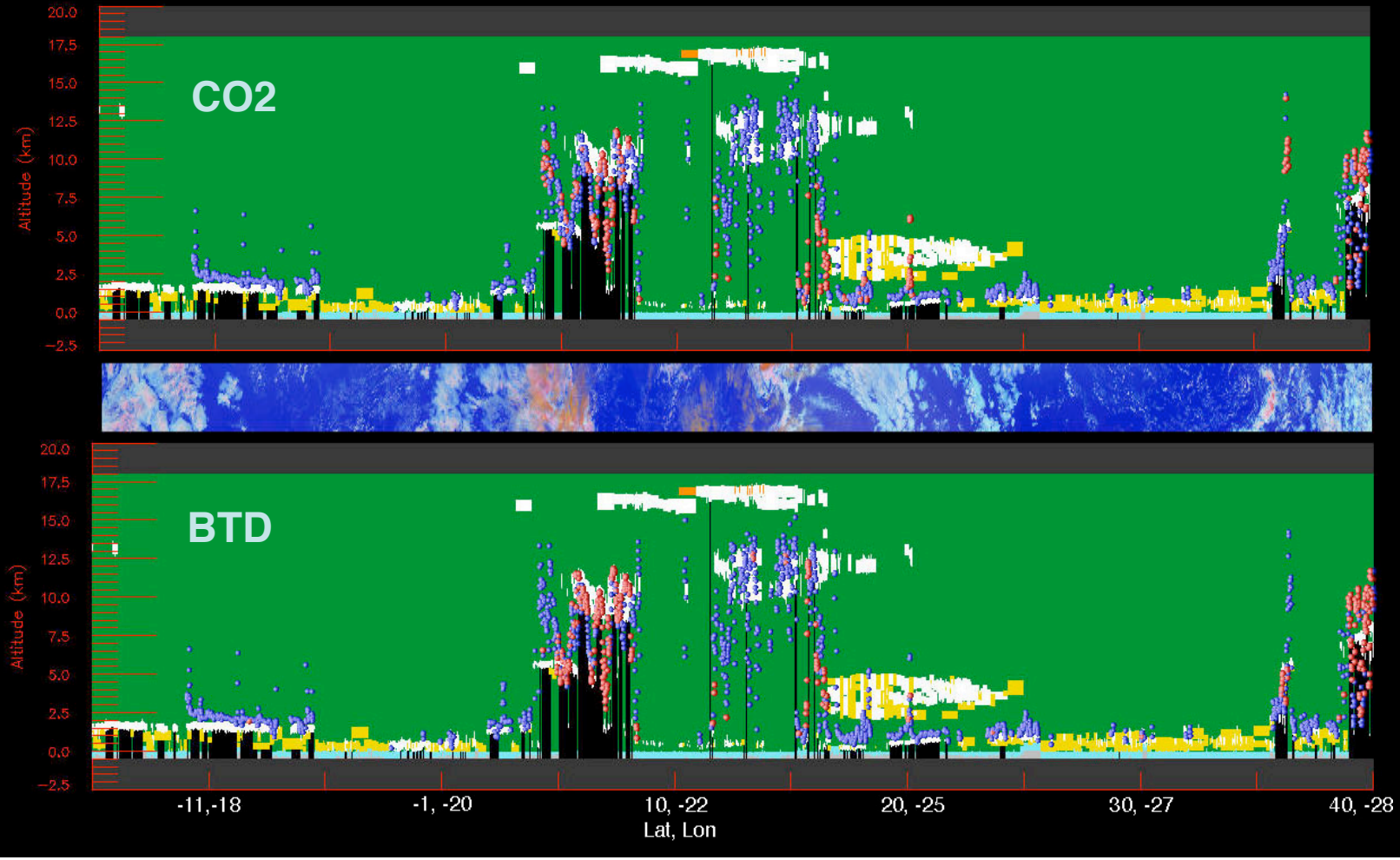

Comparison Between Two Multilayer Identifications (CO2 and BTD), merged with Calipso Cloud Type
Aug. 8, 2006, Hour 01
CERES Multilayer
CERES Single Layer
Deep Convective
Cirrus
Altostratus (opaque)
Altocumulus (transparent)
Low, broke cumulus
Transition stratocumulus
Low overcast (opaque)
Low overcast (transparent)
Cloud Type
CO2 Multilayer Identification
BTD Multilayer Identification
Altitude (km)
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0

clear
cloud
aerosol
strat feat
sfc
sub-sfc
attenuated
• single
• multi

Comparison Between Two Multilayer Identifications (CO2 and BTD), merged with Calipso Cloud Type

Aug. 8, 2006, Hour 15





clear
cloud
aerosol
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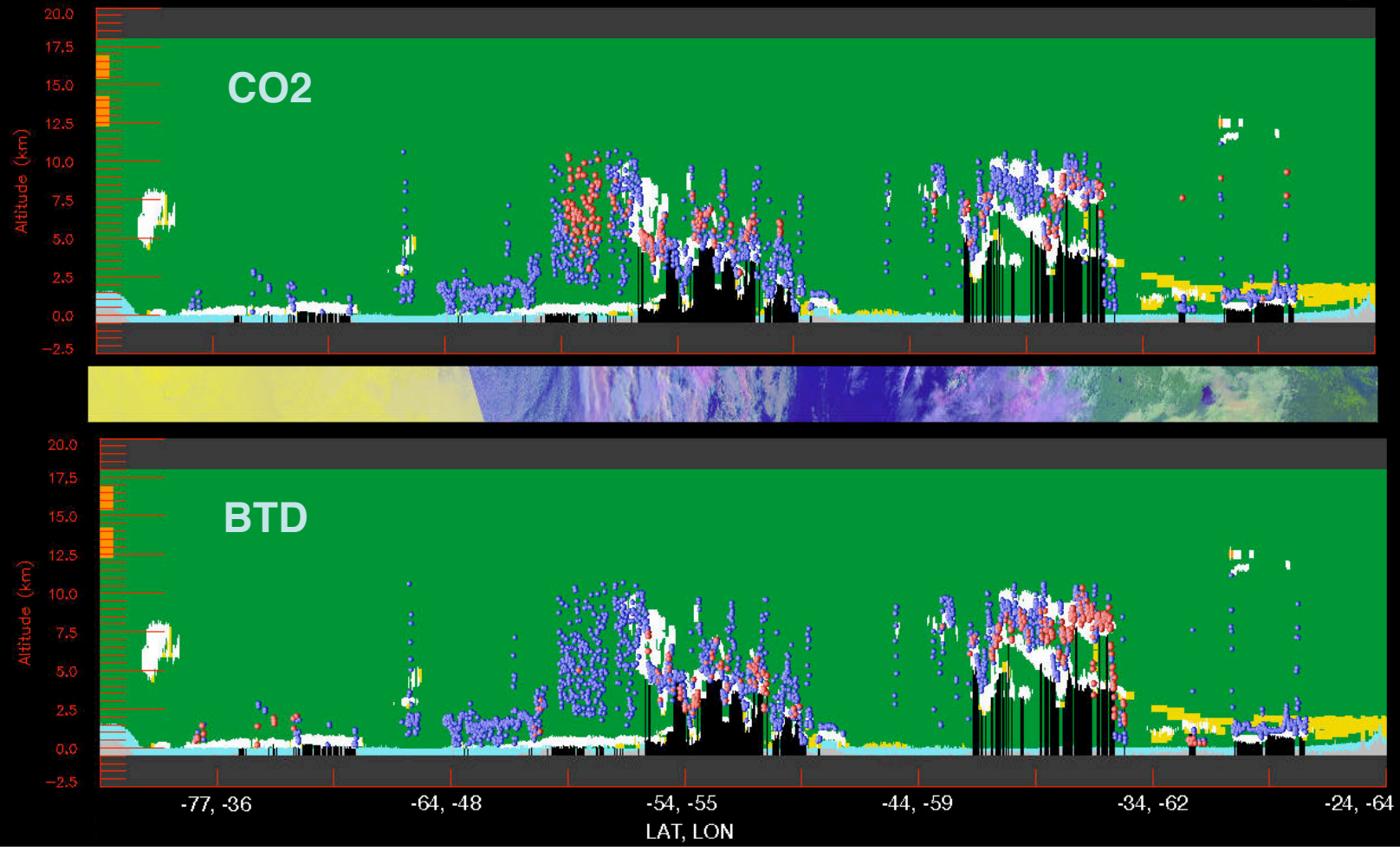
sfc
sub-sfc
attenuated
• single
• multi

Comparison Between Two Multilayer Identifications (CO2 and BTD), merged with Calipso Cloud Type

Aug. 8, 2006, Hour 18



Preliminary Detection Statistics, 8 August 2006, day, non-polar

CALIPSO	ML		SL		Conv		Clear	
	BTD	CO2	BTD	CO2	BTD	CO2	BTD	CO2
2 km ML	0.23	0.12	0.56	0.66	0.04	0.06	0.17	0.16
SL	0.06	0.11	0.52	0.44	0.01	0.02	0.41	0.43
3 km ML	0.25	0.14	0.57	0.68	0.03	0.05	0.15	0.14
SL	0.07	0.14	0.52	0.41	0.02	0.04	0.39	0.41
4 km ML	0.25	0.15	0.58	0.68	0.02	0.04	0.14	0.14
SL	0.09	0.16	0.51	0.39	0.03	0.05	0.37	0.40
5 km ML	0.25	0.16	0.60	0.68	0.01	0.03	0.15	0.14
SL	0.10	0.18	0.51	0.37	0.03	0.06	0.35	0.39

2 km: 51% ML; 3 km: 42% ML; 4 km: 36% ML; 5 km: 31% ML

For 2 km separation, day + night, CALIPSO has 38.7% ML, 40.4% SL, 20.9% CLR

CONCLUDING REMARKS

- **Preliminary results not too encouraging**
  - 50-60% of CALIPSO ML clouds classed as SL by passive methods
  - BTD picks up 25% of ML clouds; CO2 only ~15%
  - ~ 10% false ML clouds
  - overestimate of clear scenes

- **But wait! There is much more to consider.**
  - preliminary algorithms, CO2 method not fully integrated into CERES
  - optical depths, CALIPSO sees nearly everything (~16% clouds; $\tau < 0.3$)

    MODIS retrievals typically detect only $\tau > 0.3$
  - passive methods applicable to limited range of conditions
  - aerosol-cloud uncertainties in CALIPSO mask (initial release)
  - comparisons will be used to optimize passive methods

Future Research

- **Address the discrepancies**
  - finish integration & testing of passive methods
  - break down results by layer optical depths
  - refine detection thresholds
  - reduce false returns
- **Add CloudSat cloud profiles and information**
- **Validate & refine ML cloud retirevals**
- **Merge retrievals for every CERES field of view**
- **Merge w/ AMSR-E; perform additional ML cloud analyses**