

Diurnal variability of marine boundary-layer cloud system types as seen from Terra and Aqua satellites

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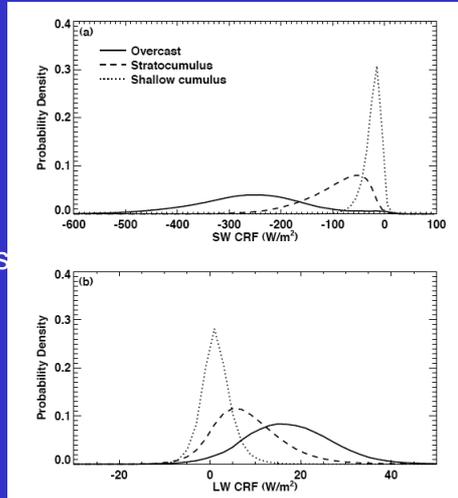
Background

- Boundary-layer (BL) clouds mainly reflect solar radiation, and directly impact the surface energy budget and upper ocean circulations
- BL cloud types include marine cumulus, stratocumulus, overcast stratus, and fogs with varying *vertical thicknesses* and *cloud-top heights*
- BL clouds are identified as one of the leading causes of uncertainties in predicting climate sensitivity (particularly, cloud feedbacks) to anthropogenic forcings (IPCC AR4)
- Diurnal variability is the most dominant mode of variability
- Terra (10:30 am) and Aqua (1:30 pm) polar-orbiting satellites sample the same cloud fields at different time of the day

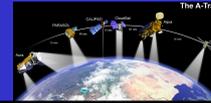


Cloud radiative effect: Why do you care of different boundary-layer cloud types?

CERES footprint data (20x20 km²) on NASA Terra and Aqua satellites



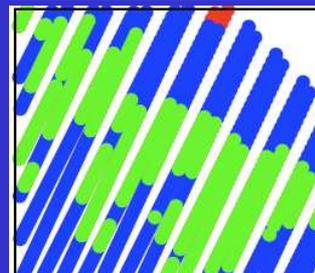
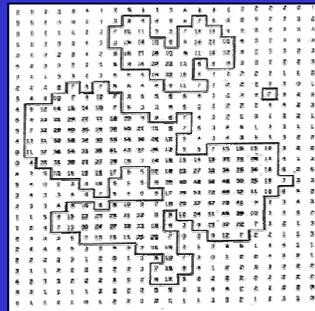
Eitzen, Xu and Wong (2008; *J. Climate*)



What is a cloud object?

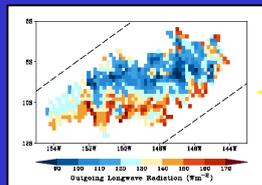
(Xu *et al.* 2005, 2007, 2008)

- A **contiguous patch** of cloudy regions with a single dominant cloud-system type; **no mixture of different cloud-system types**
- The shape and size of a cloud object is determined by
 - the satellite footprint data
 - the footprint selection criteria
- For example, selection criteria for boundary-layer cloud object types:
 - Cloud top height $z_{top} < 3$ km, and
 - Footprint cloud fraction: 0.1-0.4 **cumulus**, 0.4-0.99 **stratocumulus**, and > 0.99 **overcast stratus**

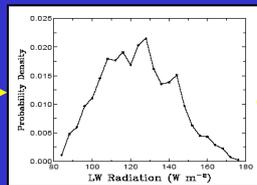


Advantages of cloud object analysis

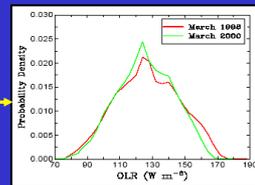
- Lagrangian approach (“snapshot”) compared to the Eulerian approach with the gridded monthly mean data
- Reduces the cloud variabilities by grouping data from the same cloud-system type
- Reduces the sampling/weather noises by combining data from a wide range of geographic regions
- Isolates diurnal variability for specific types of cloud systems in terms of frequency of occurrence and cloud physical/radiative property frequency distribution functions (PDFs)



Cloud Object



Single PDF

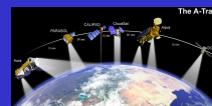


Combined PDF

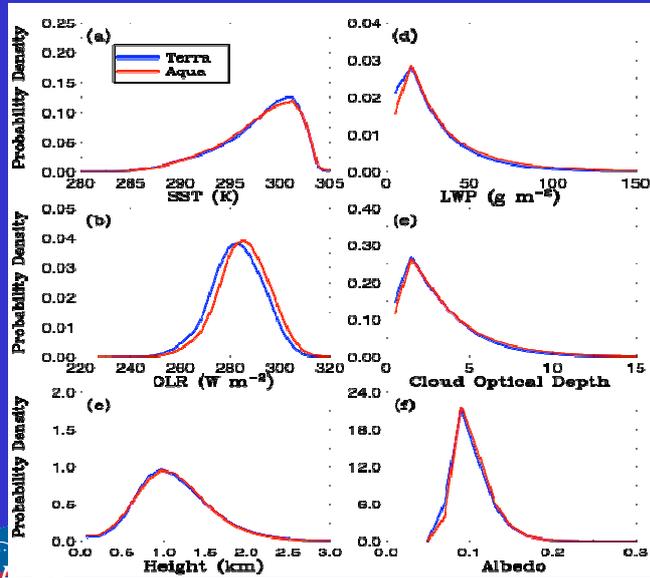


Summary, 1

- One-year data period: July 2002 – June 2003 for Terra (10:30 am) and Aqua (1:30 pm); oceanic regions of 40 S – 40 N
- Total numbers of identified cloud objects are 6.72% higher (380K vs. 354K) in Terra than in Aqua, while total numbers of footprints for all cloud objects are 17.05% higher (28M vs. 23M) in Terra than in Aqua (for cloud objects with equivalent diameters of greater than 75 km)



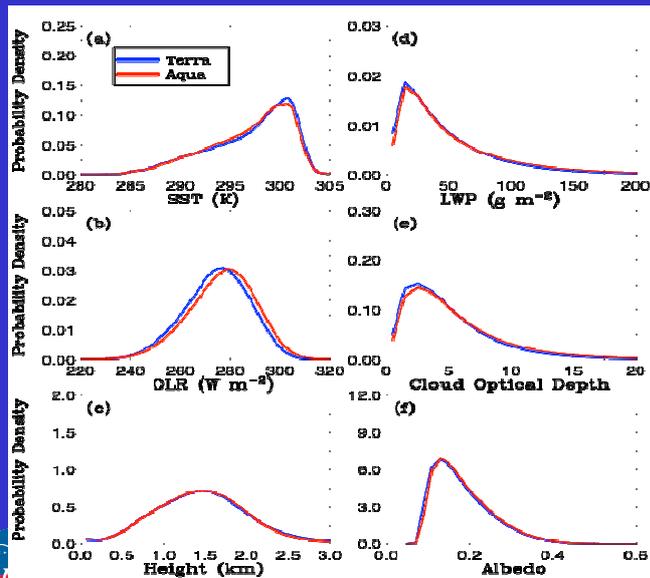
Cumulus cloud objects with sizes of 75-150 km



Cumulus 0.1-0.4	Stratocu 0.4 - .99	Overcast 0.99-1.0
138,119	90,250	40,166
-8.5%	-1.3%	-6.0%
2,943K	1,965K	862K
-8.2%	-2.3%	-6.1%



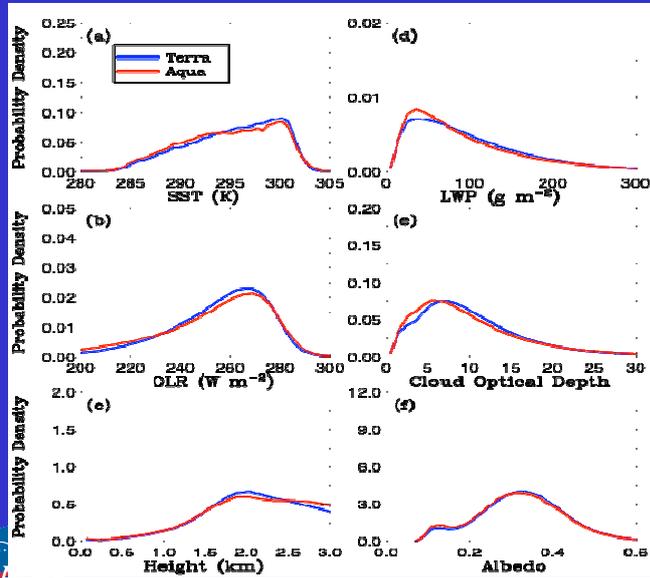
Stratocumulus cloud objects with sizes of 75-150 km



Cumulus 0.1-0.4	Stratocu 0.4 - .99	Overcast 0.99-1.0
138,119	90,250	40,166
-8.5%	-1.3%	-6.0%
2,943K	1,965K	862K
-8.2%	-2.3%	-6.1%



Overcast cloud objects with sizes of 75-150 km



Cumulus 0.1-0.4	Stratocu 0.4 - .99	Overcast 0.99-1.0
138,119 -8.5%	90,250 -1.3%	40,166 -6.0%
2,943K -8.2%	1,965K -2.3%	862K -6.1%

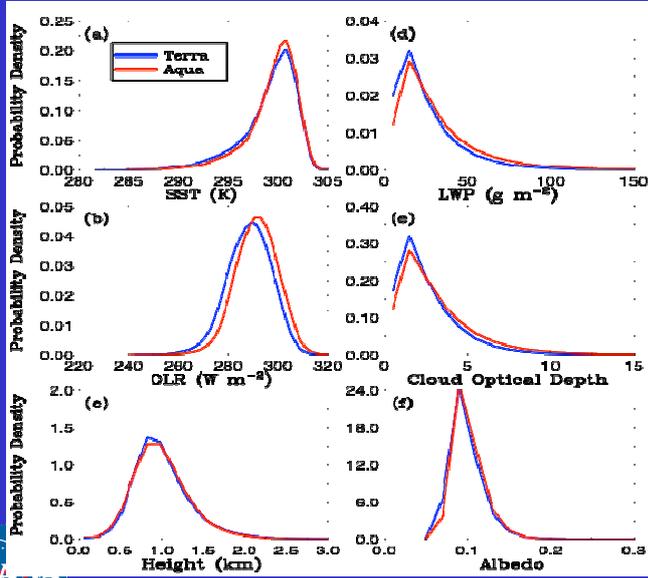


Summary, 2

- For the smallest size category (75 – 150 km), cloud physical/radiative property PDFs are rather similar between Terra and Aqua, except for OLR



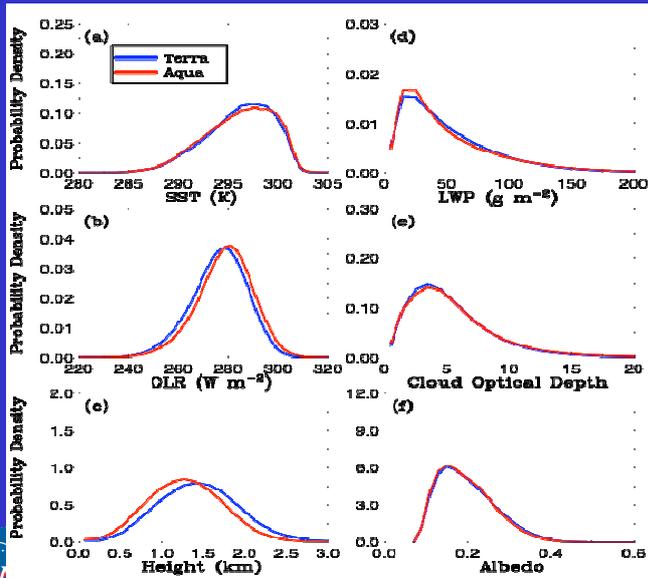
Cumulus cloud objects with sizes of > 300 km



Cumulus 0.1-0.4	Stratocu 0.4 - .99	Overcast 0.99-1.0
8,417 +5.5%	13,524 -24.7%	6,806 -20.1%
3,178K +8.8%	7,870K -35.1%	4,369K -33.1%



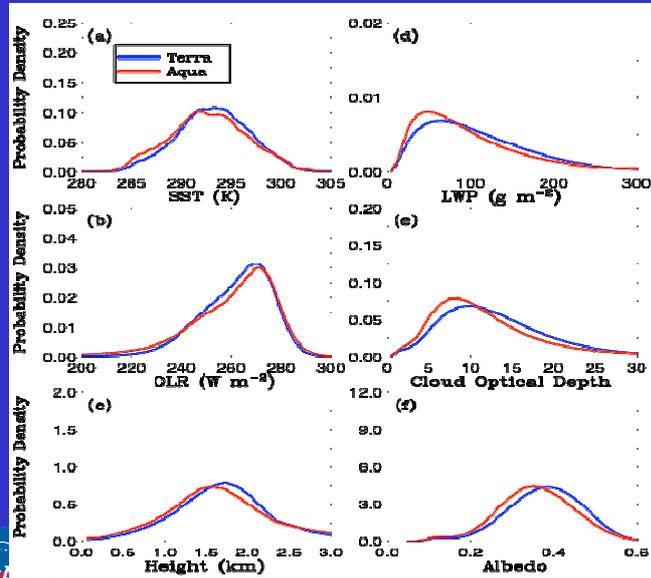
Stratocumulus objects with sizes of > 300 km



Cumulus 0.1-0.4	Stratocu 0.4 - .99	Overcast 0.99-1.0
8,417 +5.5%	13,524 -24.7%	6,806 -20.1%
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Overcast cloud objects with sizes of > 300 km



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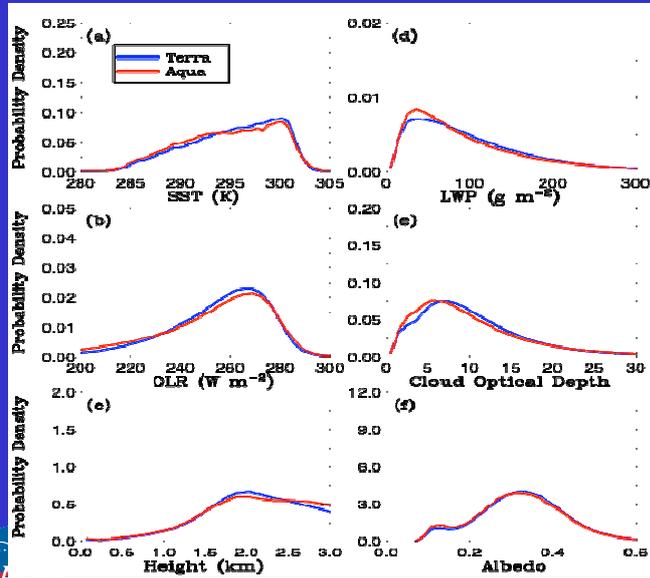


Summary, 3

- For the large size category (>300 km), differences in cloud physical/radiative property PDFs between Terra and Aqua are more pronounced for cumulus and overcast cloud object types
- Transition from *more cloudy* types to *less cloudy* types (e.g., stratocumulus to cumulus) is seen in cloud microphysical properties and this occurs over warmer oceanic regions
- Number of cumulus cloud objects and footprints are greater in Aqua than in Terra, but much smaller for stratocumulus and overcast types



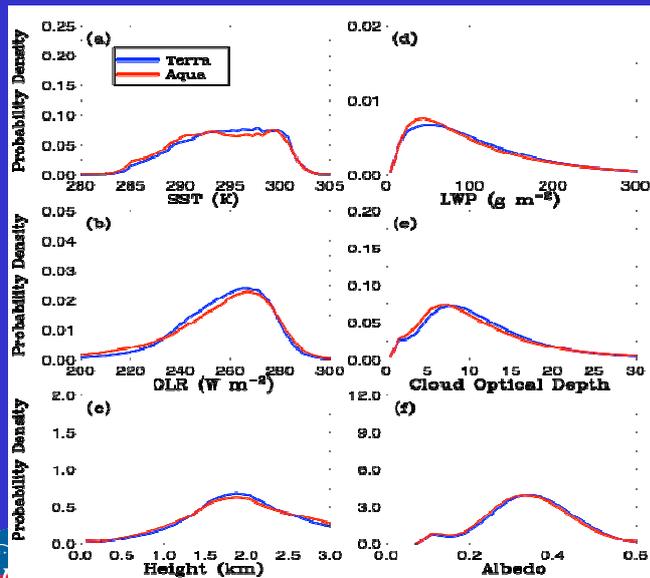
Overcast cloud objects with sizes of 75-150 km



Terra (#)	Δ (Aqua - Terra)
40,166	-5.96%
862K	-6.14%



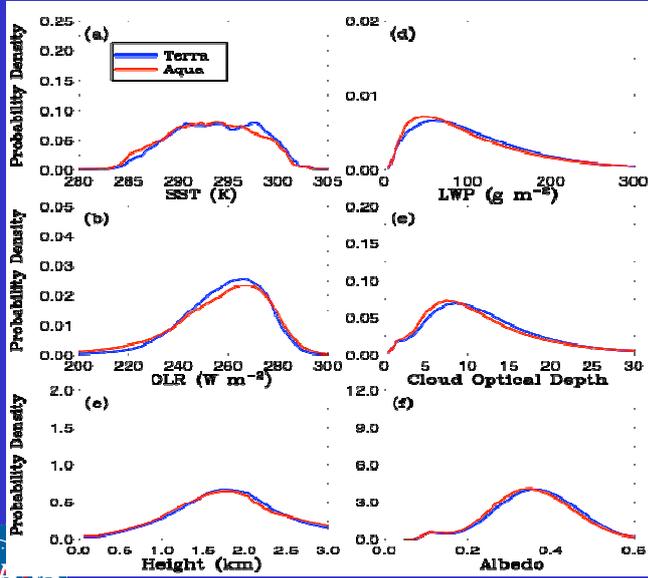
Overcast cloud objects with sizes of 150-300 km



Terra (#)	Δ (Aqua - Terra)
13,146	-6.31%
1,129K	-7.45%



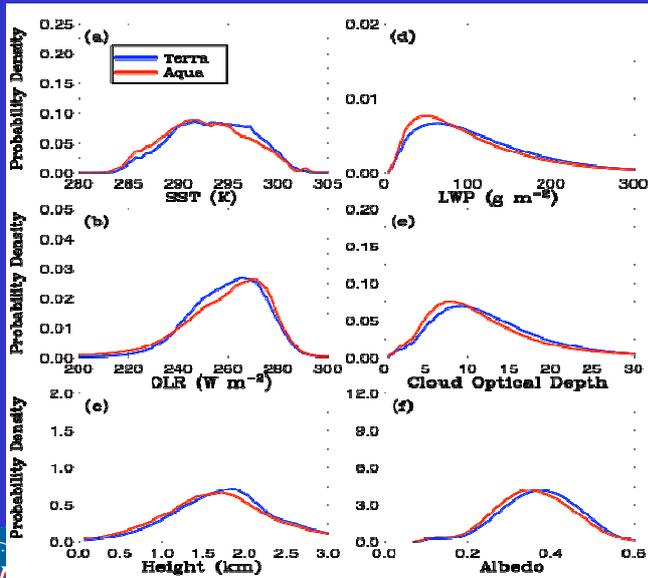
Overcast cloud objects with sizes of 300-450 km



Terra (#)	Δ (Aqua - Terra)
3,400	-7.44%
890K	-7.82%



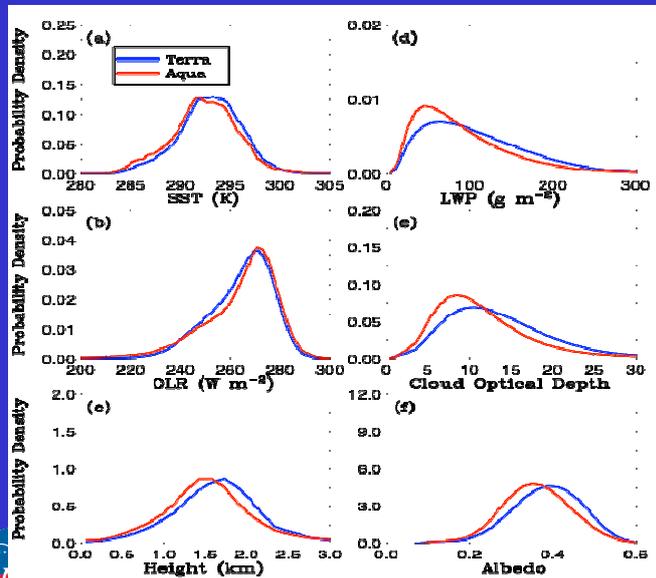
Overcast cloud objects with sizes of 450-650 km



Terra (#)	Δ (Aqua - Terra)
1,779	-16.6%
1,010K	-17.8%



Overcast cloud objects with sizes of > 650 km



Terra (#)	Δ (Aqua - Terra)
1429	-43.2%
2,470K	-48.4%

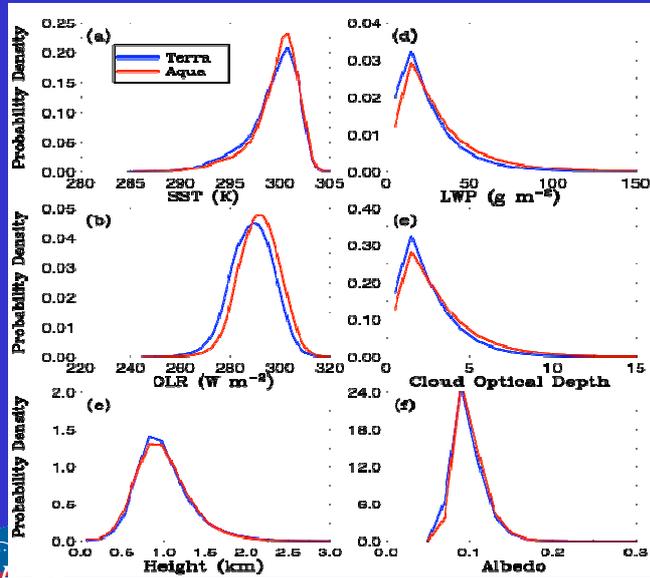


Summary, 4

- For the overcast cloud object type, the number of cloud object and total footprint numbers become (relatively) smaller in Aqua than in Terra as the cloud object size increases, in particular, between > 450 km and < 450 km size categories
- Differences in cloud physical/radiative property PDFs between Terra and Aqua become more pronounced as the cloud object size increases, due to breakup of large cloud objects and transition to less cloudy types



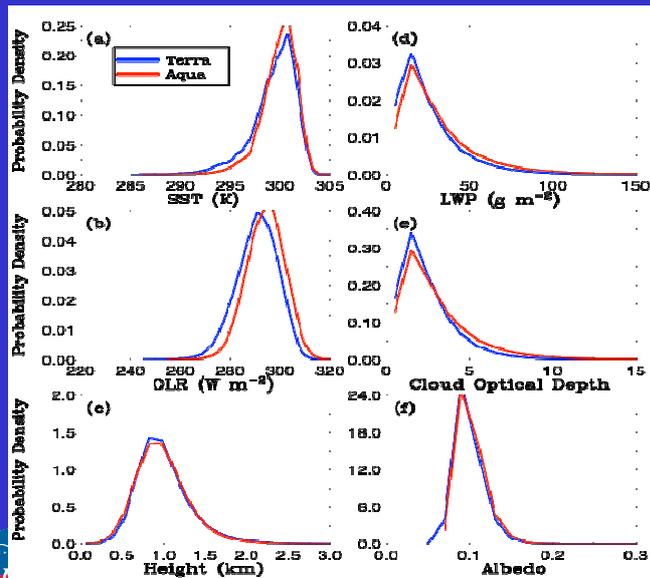
Cumulus cloud objects with sizes of 450-650 km



Terra (#)	Δ (Aqua - Terra)
1,887	+13.8%
1,027K	+14.9%



Cumulus cloud objects with sizes of > 650 km



Terra (#)	Δ (Aqua - Terra)
511	+19.4%
612K	+17.0%



Summary and conclusions

- Large stratocumulus and overcast stratus cloud objects break up into smaller ones, transitions from stratocumulus to cumulus types and from overcast stratus to stratocumulus types occur as observational time changes from morning to afternoon.
- Substantial contrasts in cloud and radiative properties exist between Terra and Aqua measurements
 - For cumulus type, transition from stratocumulus type occur in warmer SST regions; increases in cloud optical depth and liquid water path in Aqua are due to the transition of cloud types
 - For stratocumulus and overcast types, the Aqua cloud optical, liquid water and albedo are smaller (cloud thinning) than the Terra counterparts; most pronounced in the larger size categories
 - Higher OLRs for cumulus and stratocumulus types, but shallower cloud tops for stratocumulus and overcast types in Aqua

