CLOUD OBSERVATIONS FROM ICESAT, AND COMPARISON WITH ECMWF MODEL-GENERATED CLOUDS

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INTRODUCTION:

The Geoscience Laser Altimeter System (GLAS) orbits the earth onboard the Ice, Cloud and Land Elevation Satellite (ICESat). ICESat travels at ~7 km/s ground speed in a near-polar orbit. GLAS emits laser pulses at a 40Hz rate, resulting in a backscatter cross section of the atmosphere with vertical resolution of 76.8 m, and a distance between laser footprints of 175 m. Peaks in the laser's backscatter profile mark the boundary layer top, clouds and elevated aerosol layers. Averaging several backscatter profiles together increases the signal-to-noise ratio and improves cloud and aerosol layer detection, but at the expense of horizontal resolution. The laser's signal may become fully attenuated in optically thick clouds (such as boundary layer clouds and deep convective clouds), yet it easily penetrates optically thin clouds, like cirrus.

OBJECTIVES:

Our goal is the evaluation of the ECMWF model clouds through comparison with the GLAS-observed clouds. In particular, we focus here on marine boundary layer clouds.

STRATEGY:

GLAS can accurately detect the vertical and horizontal location of clouds, but it knows little about cloud microphysics. From a combination of cloud fraction and cloud top height, we can infer the observed cloud type (see below). We use the GLAS data to answer the following questions:

- Does the ECMWF model produce Sc clouds in the observed areas?
- Does the model-generated cloud top height agree with the observations?
- Does the generated cloud have the same characteristics as the observed clouds?

SELECTION CRITERIA FOR CLOUD TYPE:

Marine stratocumulus (Sc) and trade cumulus (TCu) clouds exist primarily in the subtropical eastern ocean basins. To classify the observed and modeled clouds, we consider only samples over ocean within these regions (see boxes in Fig. 1a). Further, we require that samples to be classified "Sc" have:

- more than 80% cloud fraction, and
- cloud tops below 2km.

To qualify as a "TCu" cloud sample, we require

- less than 80% cloud fraction, and
- cloud tops below 3km.

REFERENCES:

Klein, S. A. and D. L. Hartmann, 1993: The Seasonal Cycle of Low Stratiform Clouds. J. Climate, 6, 1587-1606.

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Zwally, H.J., R. Schutz, S. Palm, W. Hart, S. Hlavka, J. Spinhirne, and E. Welton. 2006. GLAS/ICESat L2 Global Planetary Boundary Layer & Elevated Aerosol Layer Heights V026 and GLAS/ICESat L2 Global Cloud Heights for Multilayer Clouds V026, 26 September to 18 November 2003. Boulder, CO: National Snow and Ice Data Center. Digital media.

ACKNOWLEDGMENTS:

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Sc observed by ICESat

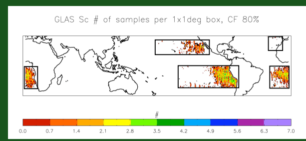

Fig. 1a

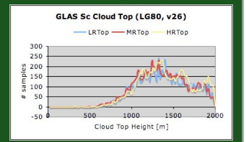

Fig. 1b

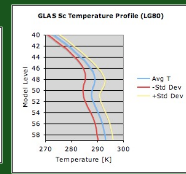

Fig. 1c

A total of 7994 samples can be found in the GLAS data spanning 54 days from Sep 26th to Nov 18th 2003 that fulfill the conditions to be classified "Sc". The samples are found in the easternmost parts of the subtropical ocean basins, close to the coast (Fig. 1a). The corresponding cloud tops range in height between ~1 and 2km, with a broad maximum around 1300m (Fig. 1b). A composite plot of the temperature profiles for all Sc samples (Fig. 1c) shows a temperature inversion of ~1.4K spanning model levels 48 through 51 (corresponding approximately to 620m and 1220m respectively).

"old" model run

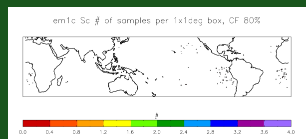

Fig. 2a

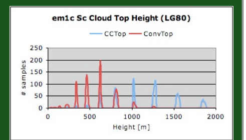

Fig. 2b

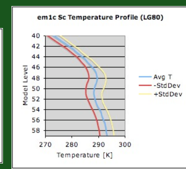

Fig. 2c

In the "old" (CY28R3) version of the ECMWF model, Sc clouds are generated by the shallow cumulus parameterization. Very few clouds with >80% cloud fraction are generated (758 Sc samples). The height to which the parameterization is active (red) is generally lower than the cloud tops observed by GLAS. However, the clouds (as measured by cloud fraction >0) extend beyond the level to which the parameterization reaches, and the actual cloud top heights are distributed similarly to the observed ones (blue, Fig. 2b). We are still investigating where those clouds above the top level reached by the parameterization come from. The composite temperature profile for the Sc samples has an inversion of approximately the same strength as from the GLAS composite (Fig. 2c).

"new" model run

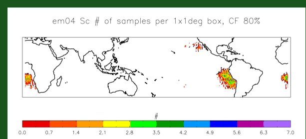

Fig. 3a

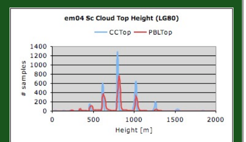

Fig. 3b

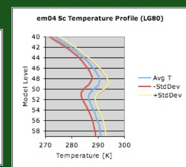

Fig. 3c

The "new" (CY29R1) model generates its Sc clouds through a combined mass flux/diffusion scheme using moist-conserved variables (ECMWF SAC report, 2004). Previously, the PBL was described by simple K-diffusion of dry-conserved variables, and could not produce clouds. Whether Sc clouds are generated by the PBL parameterization, or TCu clouds by the shallow convective parameterization depends on the Klein & Hartmann (1993) stability criterion. I.e. for Sc to be generated, the temperature difference between the 700hPa level and the surface must exceed a critical value, in this case 20K. The new parameterization produces many more Sc samples (3511) than the old version, but still only half as many as observed. The area with Sc clouds does not extend as far west (Fig. 3a), and the Sc cloud tops are on average 400m lower (Fig. 3b) than those observed. The composite temperature profile shows a stronger and lower inversion (Fig. 3c).

CONCLUSIONS FROM THE INITIAL TWO RUNS:

From the results above, it is apparent that the "new" PBL parameterization is an improvement over the "old" model version: more samples with high cloud fraction are produced. However, the "new" model still generates only half as many Sc clouds as observed, and those are located closer to the continental coasts than GLAS would suggest. The lower cloud tops in the "new" model compared to GLAS, as well as the stronger temperature inversion, can be explained in part by sampling: Closer to the coast, the trade inversion, and with it the Sc cloud tops, tend to be located lower in the atmosphere. GLAS, with more samples from the central ocean basins, includes weaker and higher inversions in its composite temperature profile. But this sampling effect cannot explain the 400m difference between the GLAS cloud tops, and the "new" cloud tops. It appears the new parameterization requires more stable conditions to generate Sc than are required in the real world. In addition, the boundary layer doesn't grow as deep in the model as observed. We found that the parcels lifted in the PBL parameterizations are strongly diluted by entrainment, and lose their energy below the observed PBL top (not shown here). To test whether these conclusions are correct, we modify the "new" parameterization and repeat the analysis:

"new/e" model run

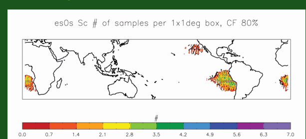

Fig. 4a

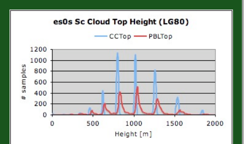

Fig. 4b

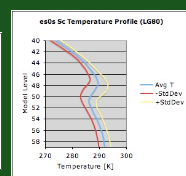

Fig. 4c

For "new/e", the formulation for the parcel entrainment has been altered from 1/(tau*wu)+0.55/z to 1/(tau*wu), where tau=500s, wu is the updraft velocity, and z is height. Both z and wu are small near the surface, resulting in strong entrainment. Leaving off the 1/z term leads to a more moderate entrainment. As a result, more samples (5087) contain Sc clouds (Fig. 4a), and the the cloud top/PBL top distribution has shifted to higher values (Fig. 4b). This is reflected in the higher temperature inversion as well.

"new/s" model run

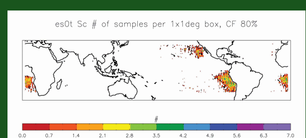

Fig. 5a

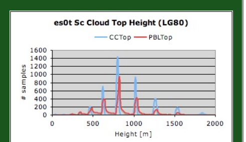

Fig. 5b

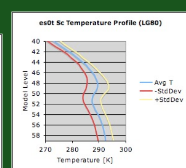

Fig. 5c

In "new/s", the Klein & Hartmann criterion has been relaxed from 20K to 16K. I.e. the PBL parameterization can now produce Sc under less stable conditions. The number of Sc samples rises to 5843, and the Sc clouds now reach further west (Fig. 5a). The cloud top distribution shifts only very slightly to higher values.

FINAL RESULTS

Both modifications to the parameterization yield results that approach the GLAS observations even further. It is interesting to note that altering the entrainment leads to an improved cloud top height distribution, while the relaxed stability criterion had a stronger influence on the sample locations. Maybe a combination of both alterations will yield even better results.