The WCR, WCL, GVR Integrated Dataset for VOCALS-REx

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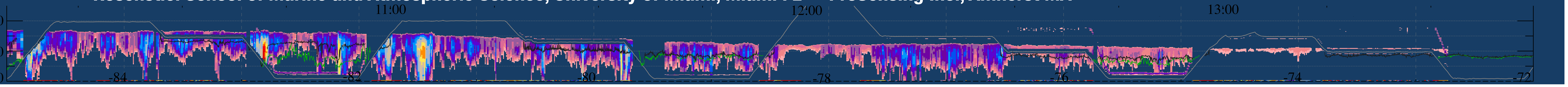


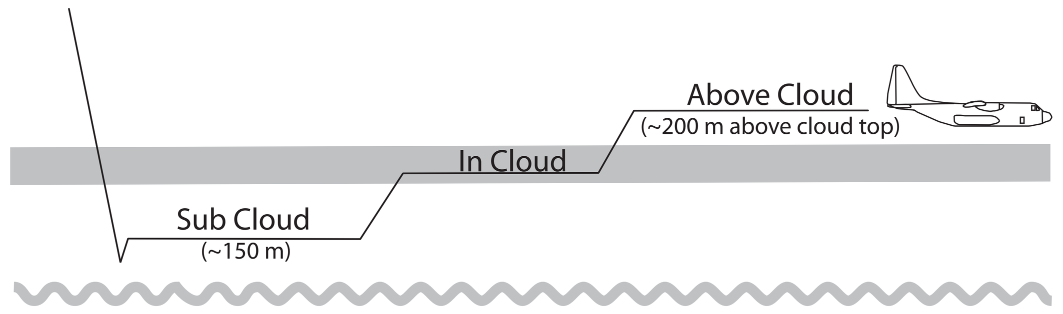
Introduction

The WCR-WCL-GVR Integrated Dataset

A suite of three remote sensing instruments was deployed on the NSF/NCAR C130 for the VOCALS-REx field campaign in October - November 2008. This suite consisted of: The Wyoming Cloud Radar (WCR), Wyoming Cloud Lidar (WCL), and a G-Band Vapor Radiometer (GVR). Combining measurements from these sensors with each other and with in situ measurements made onboard the C130 allows key quantities, such as adiabatic liquid water path, that could not be determined from a single instrument. The motivation for creating the WCR-WCL-GVR Integrated Dataset (referred to as ID or IDs) is to free users, who are often interested in a single derived product or small set of products, from having to obtain data for the individual instruments, ingest these data, and implement the desired calculations, all while avoiding a variety of pitfalls that may be well known to experienced users, but which are often not obvious to inexperienced users (prior to experiencing them firsthand).

Instrument	Acronym	Description	Configuration	Basic Products
Wyoming Cloud Radar	WCR	95 GHz dual-channel Doppler radar	3-Beams: Upward, Downward, and Down-Slant	Radar Reflectivity Doppler Velocity
Wyoming Cloud Lidar	WCL	355 nm elastic-backscatter lidar	Upward-looking Parallel and Perpendicular Channels	Attenuated backscatter
G-Band Vapor Radiometer	GVR	G-band water vapor radiometer	Upward-looking	Tb @ 183± 1,±3, ±7,±14 GHz

For most of the VOCALS-Rex flights the C130 alternated between sub-cloud, in-cloud, and above-cloud flight legs. For most C130 flights during VOCALS-Rex legs at each level were 10 min each, while for the POC flights longer legs ~40 min were used and additional levels added. Products that can be derived depend on the leg level, e.g. cloud-base from the WCL is only available for sub-cloud flight legs, while cloud-top height and Zmax (from the WCR) are available for all flight levels. Key products and the levels they are computed for are listed in the table at the top of the next column.



With the WCR & WCL being deployed for many, if not most, C130 field campaigns we believe that production of similar integrated datasets should be produced for future field campaigns (such as ICE-T in July 2011) with the specific products included varying from deployment to deployment based on the deployed instrument suite and the scientific objectives of the project. Further, selection of products for inclusion in these datasets should be considered alongside flight plans and logistical issues as a routine part of the pre-deployment planning process.

While a significant number of VOCALS participants are already using the WCR-WCL-GVR IDs in their research, others may not be simply because they are unaware of this dataset. Thus, the objective of this presentation is to raise the awareness of the integrated dataset and how investigators may be able to incorporate this dataset into their analysis.

The WCR-WCL-GVR IDs are currently available through anonymous ftp at:
`ftp://ftp.rsmas.miami.edu/users/pzuidema/GVRWCRWCFL`
`ftp://cat.uwyo.edu/pub/permanent/leon/VOCALS/WCR-WCL_IDS`
In the next few weeks, the WCR-WCL-GVR ID files and accompanying documentation will be uploaded to EOL.
Investigators wishing to use this dataset are encouraged to contact the authors at: leon@uwyo.edu and pzuidema@rsmas.miami.edu .

Variable	Definition	Source	Levels			Units
			sub cloud	in cloud	above cloud	
Zmax	Max reflectivity in vertical column	WCR	✔	✔	✔	dBZ
drizzle	drizzle indicator	WCR	✔	✔	✔	
cloudtop	cloud-top height	WCR	✔	✔	✔	m
WCLcloud	WCL cloud indicator	WCL	✔			
cloudbase		WCL	✔	✔*		m
LCL		In Situ	✔			m
cloudthick	cloud thickness	WCR + WCL	✔	✔*		m
LWPadiabatic	adiabatic LWC	WCR+WCL+In Situ	✔	✔*		g m^{-2}
REFFct	Effective radius adjusted to cloud top	WCR+In Situ	✔	✔		

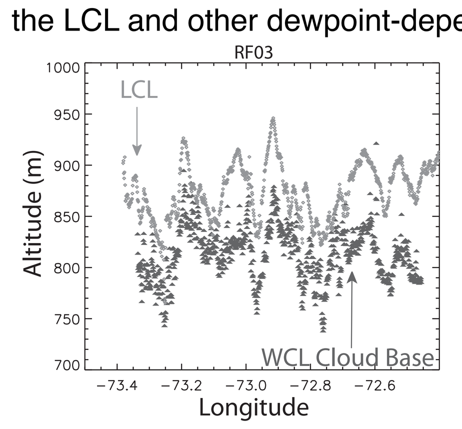
✔* For in cloud legs, cloudbase, cloudthick, and LWPadiabatic are calculated from in situ LWC assuming an adiabatic liquid water content lapse rate based on the measured temperature and pressure.

Looking for ~~Love~~ q_v in all the wrong places

Cloud Base - LCL Comparisons

The airborne atmospheric research community has long recognized the need for improved measurements of water vapor mixing ratio. Chilled mirror hygrometers have long been the standard for measuring dewpoint. While fairly accurate (dewpoints are typically assumed to be accurate to within ~±0.5 °C), chilled mirrors have slow (< 1Hz) response rates and difficulty responding to abrupt jumps in humidity. Other sensors, such as UV hygrometers, offer much better response times, but are prone to drifting and typically must be forced back to a reference measurement (typically from a chilled mirror device) over periods longer than a few minutes or tens of minutes.

Comparing the Lifting Condensation Level (LCL) computed from the in situ dewpoint, temperature, and pressure measurements using an iterative procedure with cloud base heights measured by the WCL can provide an independent check on dewpoint[1], provided the boundary layer is well mixed. To our surprise, an offset of 75 - 100 m was found with the LCL *above* the observed cloud base (this offset appeared to vary somewhat from flight-to-flight and leg-to-leg). While offsets in the opposite direction are fairly easily explainable through physical processes, offsets suggesting *higher* mixing ratios at cloud base than ~150 m above the ocean surface presumably result from instrumental issues. Based on a survey of the LCL-cloud base comparison for all subcloud legs where the boundary layer was apparently well-mixed, an offset of +0.8 °C has been added to the reported dewpoint prior to computing the LCL and other dewpoint-dependent values included in the IDs.



[1] Strictly speaking, the LCL cloudbase comparison provides a check on the *dewpoint depression* rather than on the dewpoint itself. However given the widely recognized difficulties in measuring dewpoint, we are confident that the LCL-cloud base offset results from dewpoint measurements that are biased low rather than from temperatures that are biased high.

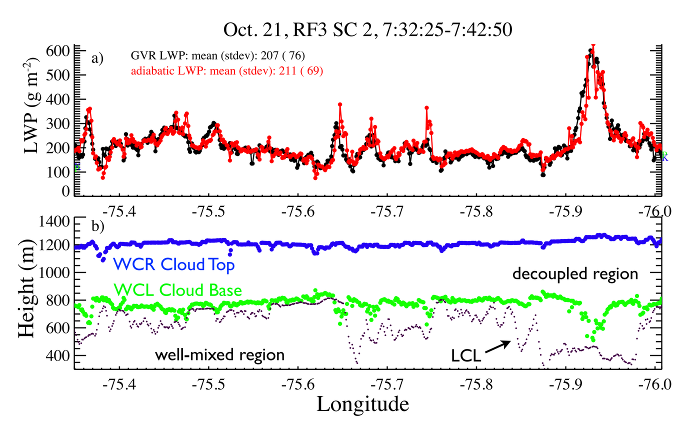
The LCL cloud base offset for a single leg. LCL and cloud base are clearly well correlated, but offset by ~75 m. Similar offsets were found for other legs, however many of the subcloud legs lacked the well-mixed segments needed for the LCL-cloud base comparison.

Radiometer Liquid Water Paths

GVR LWP Retrieval

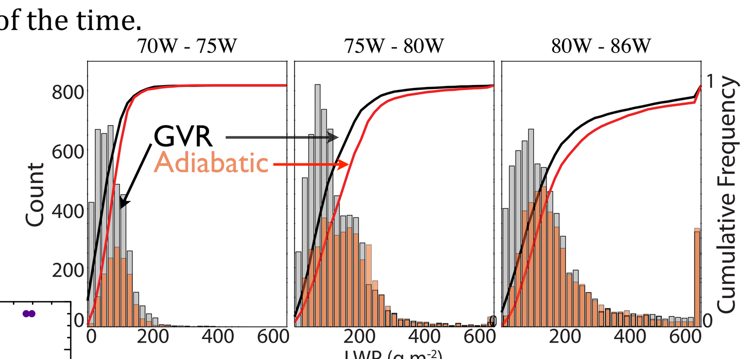
The G-band (183 GHz) Vapor Radiometer is a small, relatively inexpensive, zenith-pointing radiometer that can be mounted in a standard PMS canister. This instrument was originally designed for use in arctic conditions with very low water vapor paths. Its small size, fast response time, and accuracy that can be achieved (for low vapor paths), along with the lack of options for radiometric measurement of LWP made the GVR an appealing choice for deployment on the C130 in VOCALS-REx, despite vapor paths likely to saturate the 183 ±1, ±3 GHz channels.

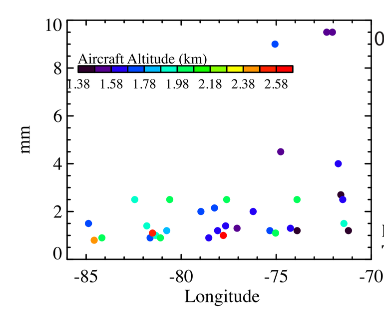
The LWP retrieval relies on an independent estimate of the boundary-layer water vapor path which is estimated from a combination of the in situ water vapor mixing ratio, the WCL cloud-base and WCR cloud-top heights. A correction of +0.8 K, added to the reported dewpoint temperature to bring the LCL into agreement with the WCL derived cloud base for coupled subcloud legs (Bretherton et al., 2010,) secured good agreement with adiabatically-derived LWPs in best-case conditions (see example below).



RF3 SC2 was selected to illustrate the comparison between the GVR-retrieved and adiabatic LWPs because it sampled a thick, yet mostly non-precipitating cloud, for which the cloud base and LCL were often closely aligned.The agreement between the two independent measures of LWP, shown in the top panel, is remarkable, especially considering the variability in LWP. (Note: timing inconsistencies between the WCL and GVR, which were not identified until after the VOCALS-REx deployment required ad hoc re-alignment of the series.)

Summary statistics from the four nighttime C-130 flights along 20S out to 85W (Oct. 21, 23, 25 and Nov. 6), subdivided by longitude, are shown below. Clouds with LWPs between 100 to 400 gm^{-2} appear to be consistently adiabatic, suggesting a higher sub-adiabatic fraction may be appropriate for SEP stratocumulus than has been reported for the N. Atlantic. For thinner clouds the WCR is often unable to determine cloud-top height (see banner figures at bottom of page), therefore adiabatic LWPs are not available. Further offshore, where LWPs are higher (consistent with precipitation) the WCR is able to determine cloud-top height most of the time.





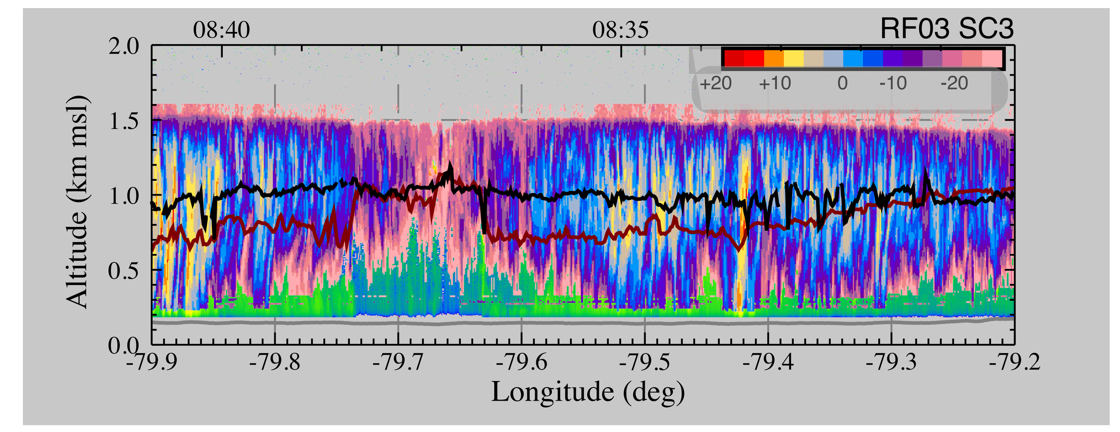
Free-tropospheric water vapor paths were retrieved for the above-cloud legs. Typical values are 1-2 mm with higher values near the coast.

The GVR LWP retrieval is described in detail in Zuidema et al. 2011 (Manuscript in preparation -- to appear in ACP/D).

Adiabatic Liquid Water Paths in Drizzling Clouds

The remarkable agreement between the GVR-derived LWP and the adiabatic LWP for clouds that are clearly drizzling (in many cases strongly) at first seems paradoxical: removal of cloud water must inevitably lead to sub-adiabatic LWPs. Wood (2005) addressed this issue by comparing the timescales for removal of cloud water due to precipitation to the replenishment through turbulent transport of water vapor through cloud base. In this treatment, cloud base remains fixed and cloud water is reduced -- That is, cloud base remains consistent with the thermodynamics of the subcloud layer, but inconsistent with the properties of the overlying cloud (parcels descending from above would reach a higher cloud base).

It should be noted that, in comparing the GVR and adiabatic LWPs, we have stealthily changed the definition of *adiabatic*. While in the conventional (strict) sense, the concept of adiabaticity applies to a parcel, here we are comparing retrieved LWP with an adiabatic value obtained from cloud base and cloud-top for the same vertical column. The timescale argument of Wood (2005) can therefore be recast such that the loss of cloud water (due either to drizzle or entrainment) is immediately reflected by changes in cloud base height.



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Acknowledgments

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This list is inevitably incomplete, while there are many individuals and institutions whose names have not been mentioned, however their contributions have not been overlooked.