Vertical Distributions of Clouds and Radiative Heating Rates in the Tropical Western Pacific

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Planning to talk about:

1. The nature of the heating rate product that we've been working on including a status report.
2. Applications of the data
3 Issues that we need to work on
4. The RH problem with the RS-92 sondes
5. I've included some closure and sensitivity tests figures at the end that I am not planning to show unless asked.

Cloud Property and Radiation Calculations

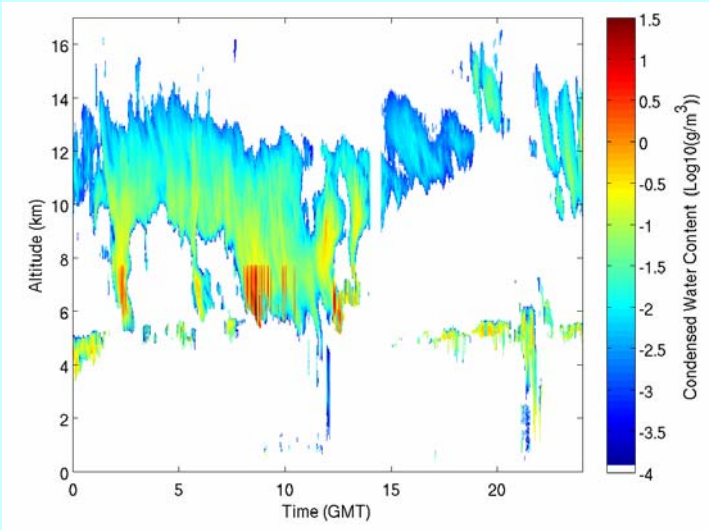
- Ice and liquid water content function of reflected radar power, Z
- Particle size function of LWC for liquid and temperature for ice
- Ice scattering properties based on Fu (1996, 1998)

- Delta 4-stream, correlated K model (Fu and Liou, 1992)
- Gas absorption based on HITRAN 2000 (Rose and Charlock, 2002)
- Vertical resolution, 45 m
- Cloud properties sampled every 5 minutes (sub-sampled)
- Lambertian surface with albedo of 0.05
- Calculations performed with and without clouds

Inputs to model are home-grown merged sounding, and version of microbase adapted to TWP – primary modification associated with treatment of mixed phase. Used current version of Fu and Liou 4-stream model for radiative transfer calculations. Ran model at 5-minute temporal resolution. We sub-sampled the cloud properties rather than averaging. We found that averaging the cloud properties led to problems in the upper troposphere – cirrus properties smeared out.

Cloud Properties: Ice + Liquid Water Content From Vertically Pointing, 35 GHz Cloud Radar

Manus: 13 March 2000



Sensitive to cloud particles

High resolution:

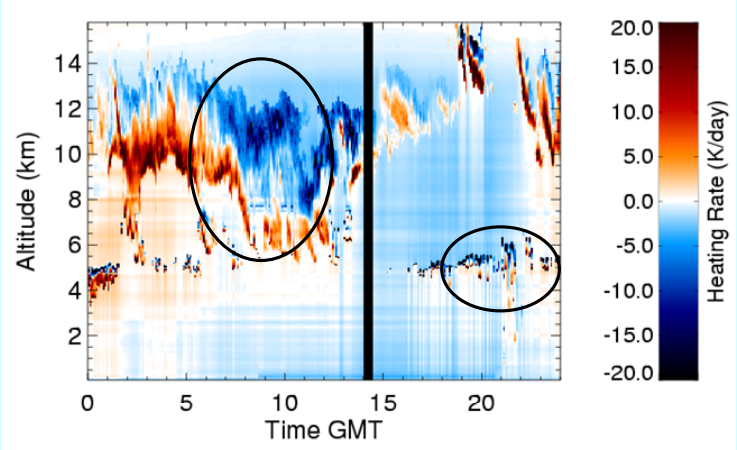
~45 m vertically

~1 minute temporally

An example cloud case. Plotting log10 of the condensed water content from tropical-microbase. Shows altocumulus at 5 km (melting level) some congestus, cirrus, and fall streaks. And possibly some mixed phase clouds around 8-13Z, 5-8 km.

This and the next few slides are meant to show an example of what the data looks like before diving into some more generalized characteristics.

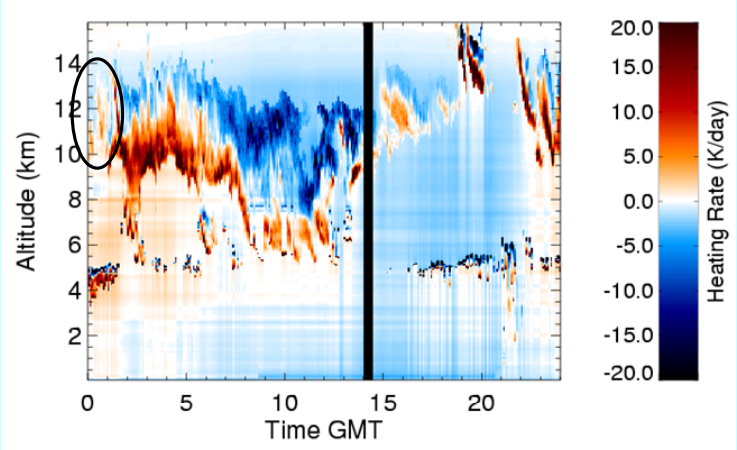
Radiative Heating Rates



Strong heating at cloud base and cooling at cloud top.

Radiative heating rates calculated using Fu code – from cloud profile shown in previous slide. Blues are cooling, reds heating. See cooling at cloud top and heating at cloud base – much of the time.

Radiative Heating Rates

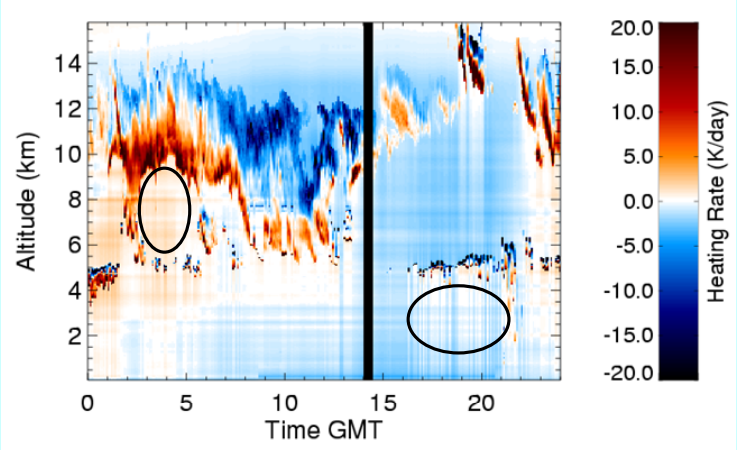


Strong heating at cloud base and cooling at cloud top.

Optically thin clouds can experience heating throughout the layer.

At times – in thin cloud – the heating extends throughout the layer. The case shown is during the day – late morning.

Radiative Heating Rates



Strong heating at cloud base and cooling at cloud top.

Optically thin clouds can experience heating throughout the layer.

Also see heating below cloud base.

Often see heating below cloud – this infrared heating associated with emission from cloud base. Normal clear sky condition is cooling through most of the column.

Data:

We have processed ~ five months of data at Manus (Mar-Jul 2000)
And 9 months at Nauru (Feb-Dec 1999)

These data are available on the PI products web page.

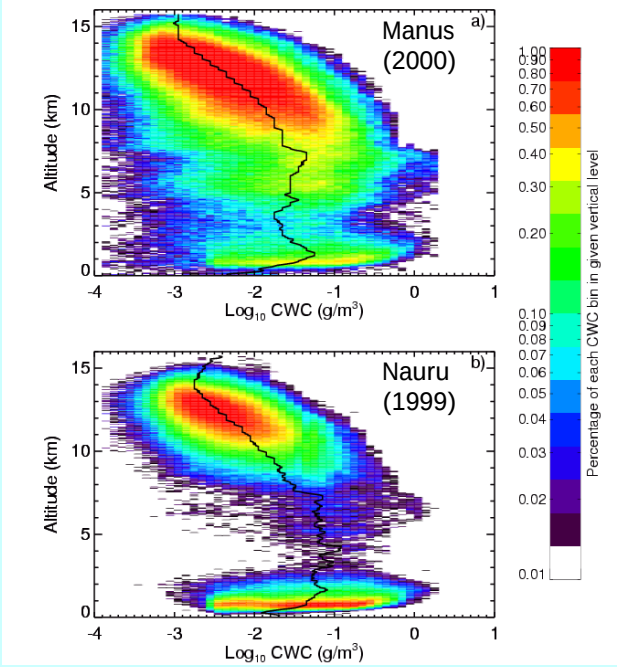
Applications

Identify characteristic structures in cloud or radiation fields for analysis of physical processes or model validation.

Eg. Long-term Frequency Distributions
Diurnal composites
Aggregate statistics by regime

We have submitted Manus and Nauru merged sounding, modified microbase, and radiative flux profiles as PI products. While there is significant work to be done with improving these data (see issues in later slide) we believe there are many useful applications of these data. They show cloud structures and associated heating structures that provide unique information for assessing models as well as fundamental physical processes. These data can be studied on a wide range of time scales from instantaneous fluxes, to diurnal composites, to long term statistics – overall or composited by meteorological regime.

Condensed Water Frequency Distributions at Manus and Nauru



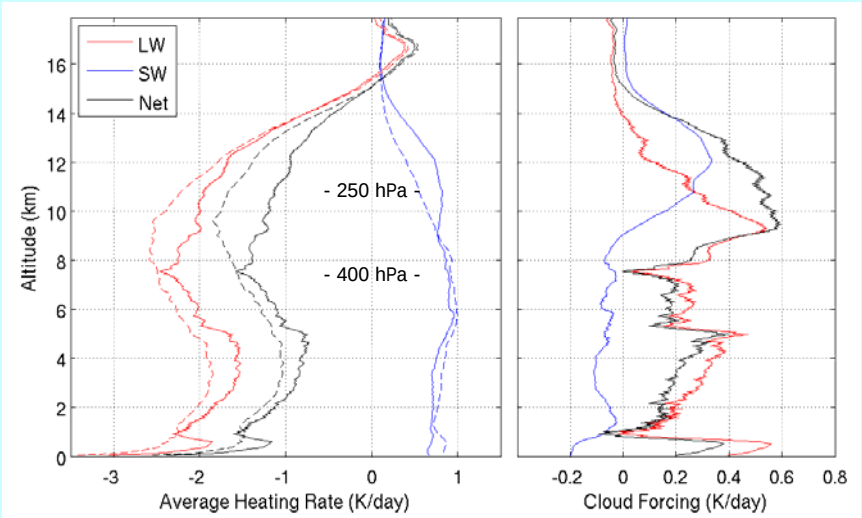
Cirrus and boundary layer features similar at Manus and Nauru.

Only Manus exhibits mid-level feature.

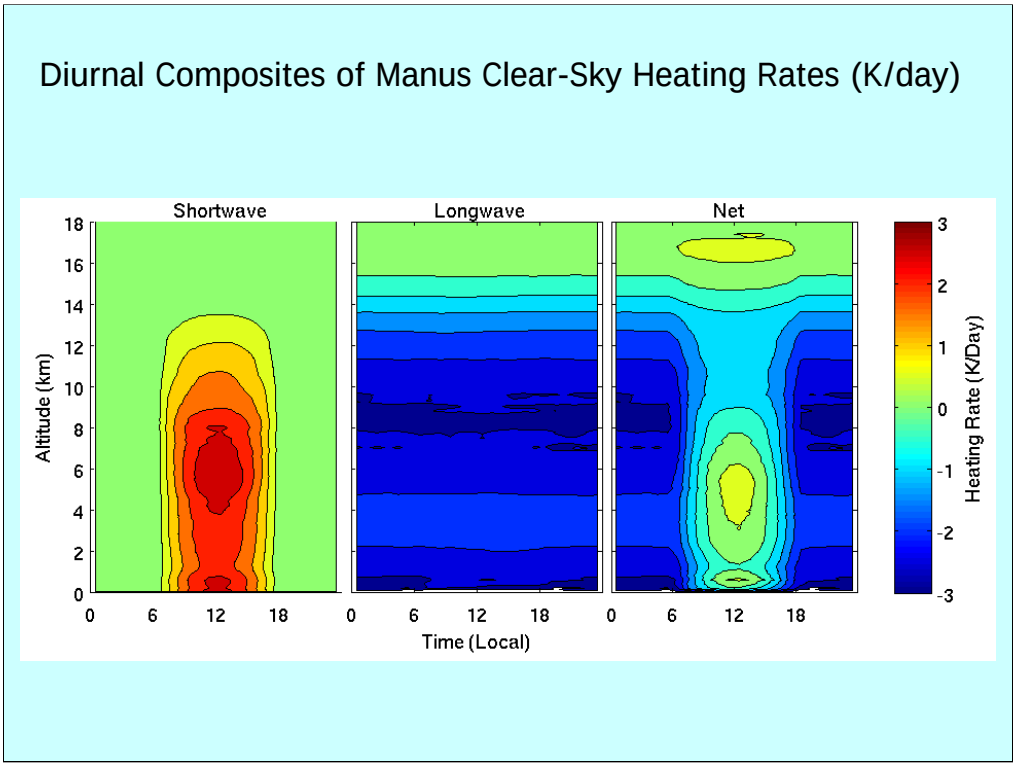
Nauru region was convectively suppressed during much of 1999.

Cloud frequency distribution for Manus and Nauru. Precipitating cases have been removed. X-axis is log10 of condensed water content (liquid content + ice content). Colors represent frequency with which a given CWC,Altitude combination occurs. Structure in boundary layer and upper troposphere are similar at the two sites but Manus has more cirrus and Nauru has more fair weather cumulus (island effect). The most significant difference is in the mid-level cloud (~4-8 km) which is generally associated with outflow from widespread convection. These stratiform clouds are common at Manus where mesoscale convective systems are common during the active phase of the MJO but are largely absent from Nauru where conditions were suppressed during 1999 (a La Nina year).

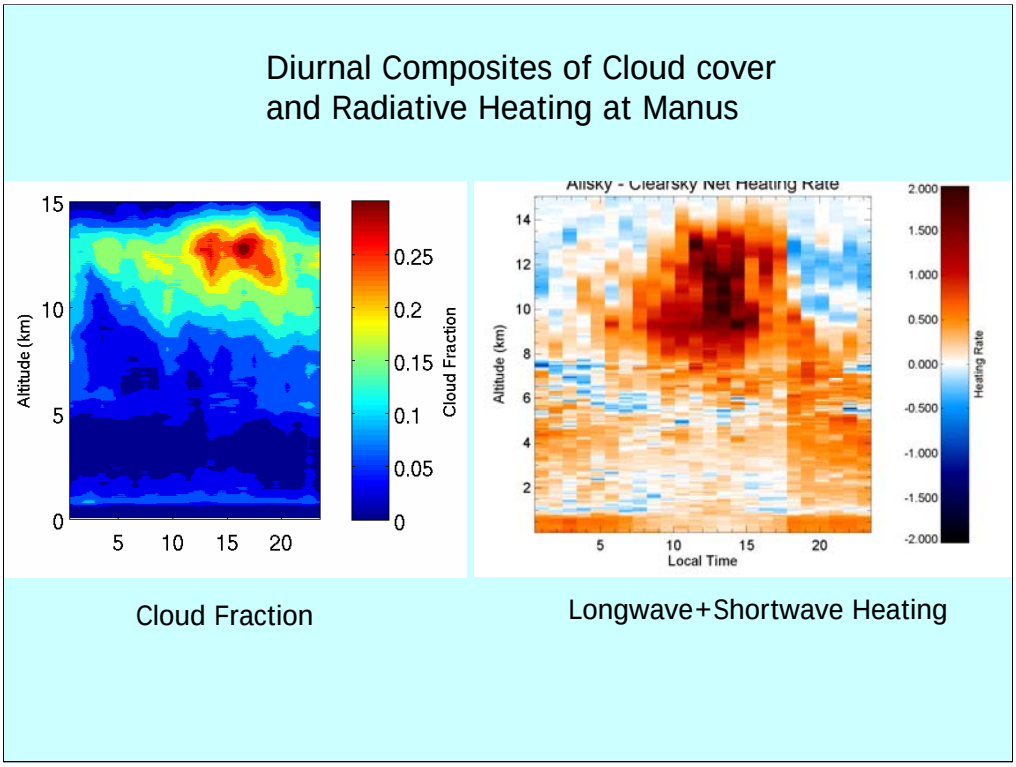
Clear and all-sky Radiative Heating Rates at Manus



Averaged heating profiles for Manus. Left panel is the heating while the right panel is the cloud effect (all-sky – clear-sky). In the left panel, the dashed lines are the clear sky profiles (red is longwave, blue is shortwave, and black is the sum of the two). Note – there is net radiative cooling – due to the longwave from the surface to ~15km. Above 15km, there is a layer of radiative heating. Through much of the column, the magnitude of the LW radiative cooling is about double the SW heating. But the cloud effect is a bit different. The LW effect is to heat through most of the column (there can be weak cooling near the tropopause – though its not obvious here). In the SW, the cloud effect is cooling from the surface to about 9 km but within the cirrus layer – the effect is heating. The different vertical structures of the LW and SW heating lead one to consider the evolution of heating over the diurnal cycle.

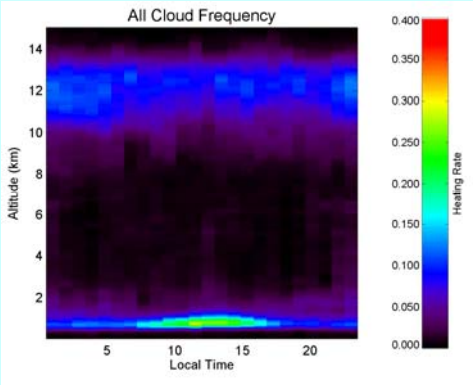


First examine the clear sky diurnal cycle (times are local). Shortwave in the left panel, Longwave in the middle, and the sum on the right. As expected, there is a strong SW diurnal cycle but very little diurnal dependence in the LW. But the most interesting thing here (I think) is the behavior of the sum. During the day – LW and SW nearly offset – but there is lots of vertical structure. This becomes more complex when clouds are added.

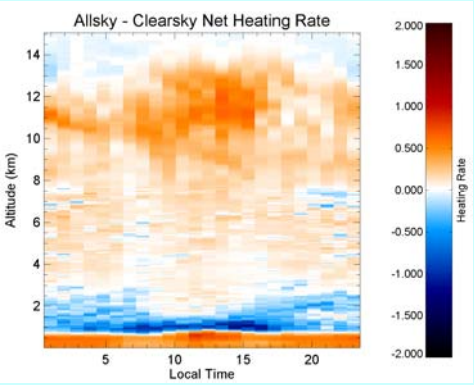


Clouds are shown at left, and the net cloud effect (LW+SW for allsky-clear sky) is shown on the right. There is a remarkably strong diurnal cycle in cirrus at Manus. Likely associated with island based convection over the large PNG islands (e.g. New Britain and maybe New Guinea itself). During the day, see deep heating in the cirrus while at night – see heating around 8-10km and cooling above – this vertical heating gradient is stronger in the evening – when clouds are more prevalent – than in the morning when clouds amount is diminished.

Diurnal Composites of Cloud cover and Radiative Heating at Nauru



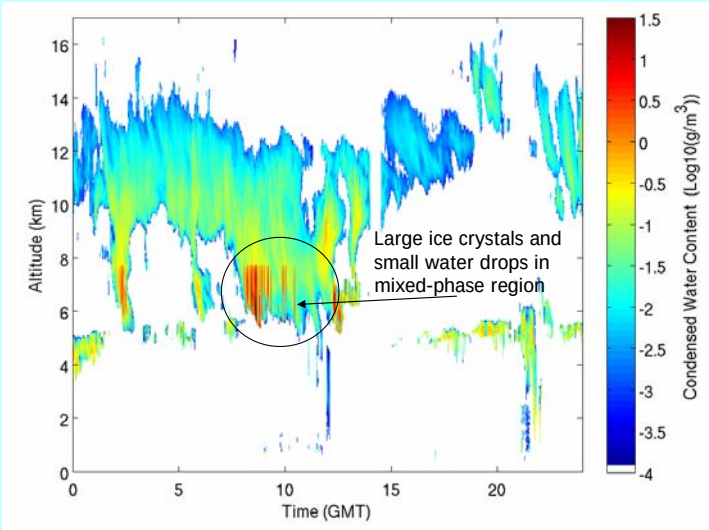
Cloud Fraction



Longwave+Shortwave Heating

At Nauru – the situation is quite different with a weak cloud minimum during the day. Still see heating through the cloud layer during the day – but don't see such pronounced cloud top cooling at night. Still – the day-night differences at both sites suggest potential diurnally forced cloud-radiation interactions.

Cloud Properties: Ice + Liquid Water Content From Vertically Pointing, 35 GHz Cloud Radar



Problem areas:

Precipitation (combine with cm radar)

Mixed phase

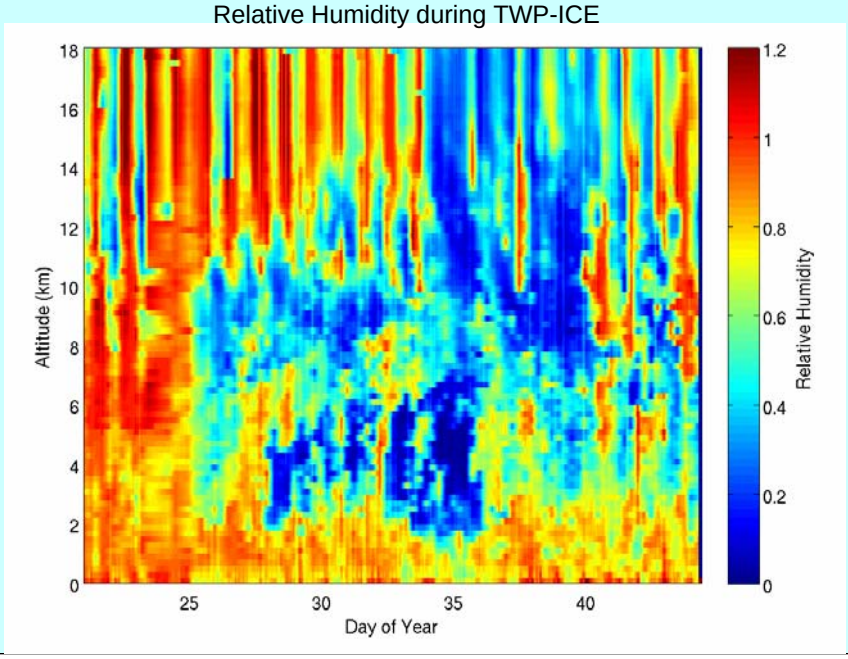
High (>15 km) cirrus with small (~20 μm) particles (combine with lidar)

Water vapor details

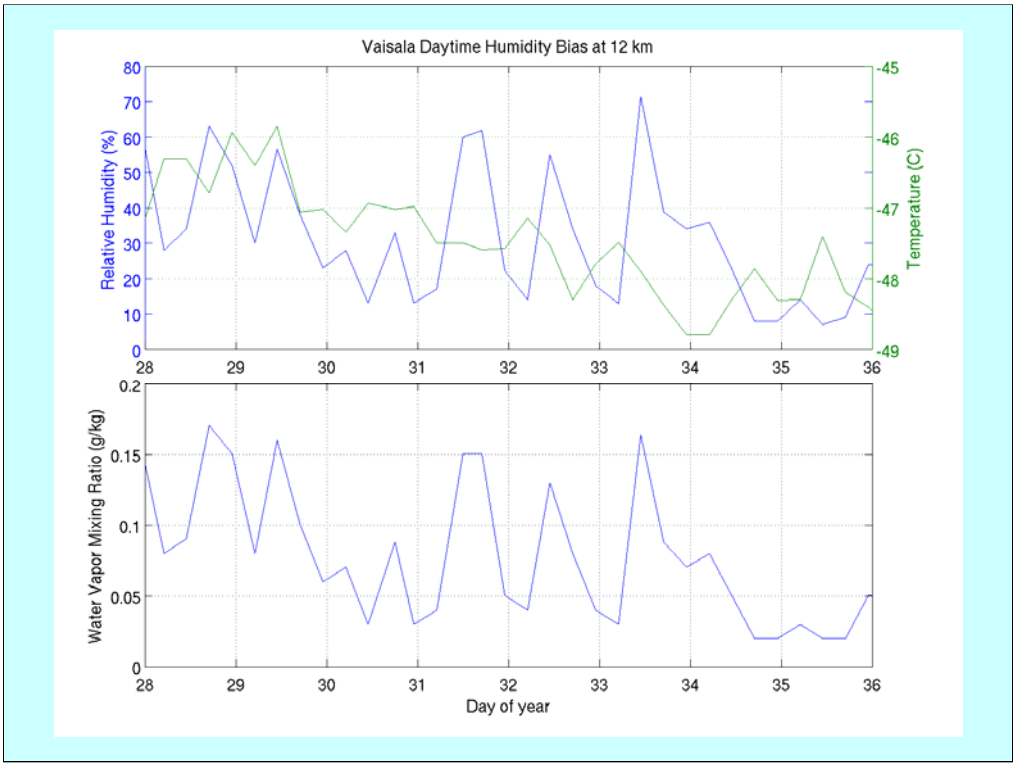
We've been looking at some of these applications – have a paper accepted in JGR with preliminary analysis and are continuing several lines of analysis. But we're also looking at the need to improve problem areas. A few that we feel are important are: dealing with precipitation, mixed-phase (a closely coupled problem) detecting high thin cirrus, and variability in water vapor. The problem with precipitation and mixed phase is that the radar is primarily sensitive to the large ice crystals and precipitation drops while the radiation is sensitive to the cloud drops. The radar may also be attenuated by precipitation. The radar will not detect very high cirrus clouds with small ice crystals – it may also miss some thin altocumulus layers. These layers may be radiatively important and need to develop a means of combining radar, lidar, and possibly satellite. We have primarily looked at general clear sky characteristics and cloud effect – looking at details of the clear sky requires accurate observations of water vapor which drives the LW cooling profile. Typically we have two launches per day so this is a real challenge. In addition – we have learned there is a significant issue with the RS-92 sonde vapor during the day.

Humidity Dry Bias in RS-92 Radiosondes

Relative Humidity during TWP-ICE



Shown here is relative humidity with respect to ice at Darwin – using the 4/day soundings at that site during TWP-ICE. Note strong oscillation un the upper troposphere.



Shown here is the Relative humidity (with respect to liquid) and temperature (top panel, RH in blue, T in green) and mixing ratio (bottom) panel. These show a strong diurnal oscillation in RH and mixing ratio (indicating this is not just a temperature oscillation effect).

Comparison of humidity from RS92
And Cryogenic Frostpoint Hygrometer.

From H. Vomel et al., submitted to
J. Atm. Ocean Tech.

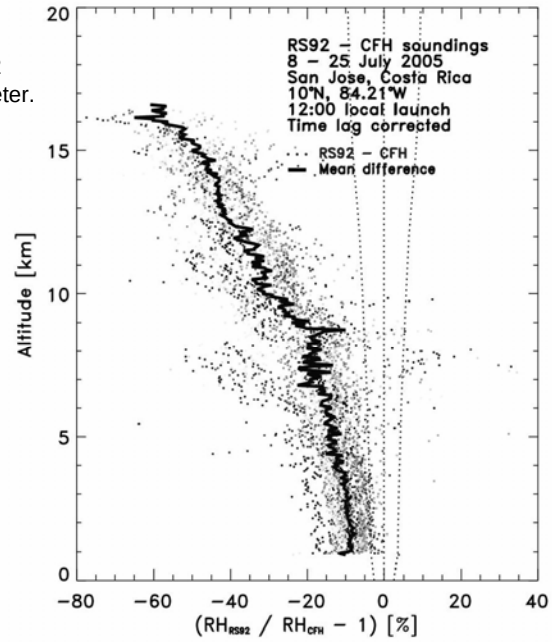


Figure 6: Relative difference between the Vaisala RS92 and CFH daytime RH.

This problem with the daytime RH in the RS-92 sondes has been noted by Holger Vomel and co-authors in a paper submitted to J. Atmosphere and Ocean Technology. This work examines flights carrying RS-92 packages along with frost point hygrometers. The experiment was from the summer of 2005 in Costa Rica. This plot shows the daytime (at high sun, SZA <~30 degrees) dry bias of the RS-92 sondes. The error is ~50% in the upper troposphere, above ~15km. The problem is more modest below ~9km so may not be a serious problem at other sites. RS-80 sondes had a covering on the thermistor which slowed down the response time of the sensor but protected the thermistor from radiative heating. The RS-92 sondes on the other hand – do not have this covering. They have a much quicker response time than the RS-80s (a good thing) but are strongly effected by radiative heating (bad!). There is also an effect on the daytime temperature – but it is a much smaller effect. Larry Milosovich is working on a general correction to this problem but it will be a challenging one since the correction will depend on the radiative heating of the sensor which will in turn depend on things such as cirrus cloud optical depth. The correction is likely to have significant uncertainties.

Conclusions

- Measurements of temperature, humidity, and cloud property profiles at tropical ARM sites provide the means to estimate radiative heating rates with high vertical and temporal resolution.

- Many applications including identification of cloud and radiative profile structures and analysis of physical processes.

- Work on the data set is on-going but can be used now.

- There is a known problem with RS-92 sondes – a daytime dry bias in the upper troposphere. This will be a problem for clear sky LW cooling profiles.

Note – the tropical sondes also need to have the time-lag correction applied for the older RS-80 sondes. This has not been done in any organized way. This correction addresses the problem of the slow time response and is thought to represent a significant improvement over the original data.

This is where I planned to stop. But I have a few additional slides – mostly closure and senstivity tests in case someone wants to see that. Or at least know that we did it.

	LW TOA (W/m^2)	LW Surface (W/m^2)	SW Albedo	SW TOA (W/m^2)	SW Surface (W/m^2)
	Manus				
Mean Observed Value	**241.6**	**419.8**	**23.9**	**221.3**	**515.4**
Mean Difference	**-0.8**	**4.5**	**3.8**	**34.7**	**-31.5**
RMS Difference	**27.5**	**6.6**	**15.8**	**158.2**	**108.9**
	Nauru				
Mean Observed Value	**274.7**	**409.6**	**15.1**	**124.9**	**547.1**
Mean Difference	**0.3**	**1.9**	**5.3**	**54.9**	**-9.8**
RMS Difference	**19.9**	**9.1**	**11.6**	**118.6**	**94.5**

Differences between calculated and observed fluxes. Flux differences are expressed as model minus observed flux.

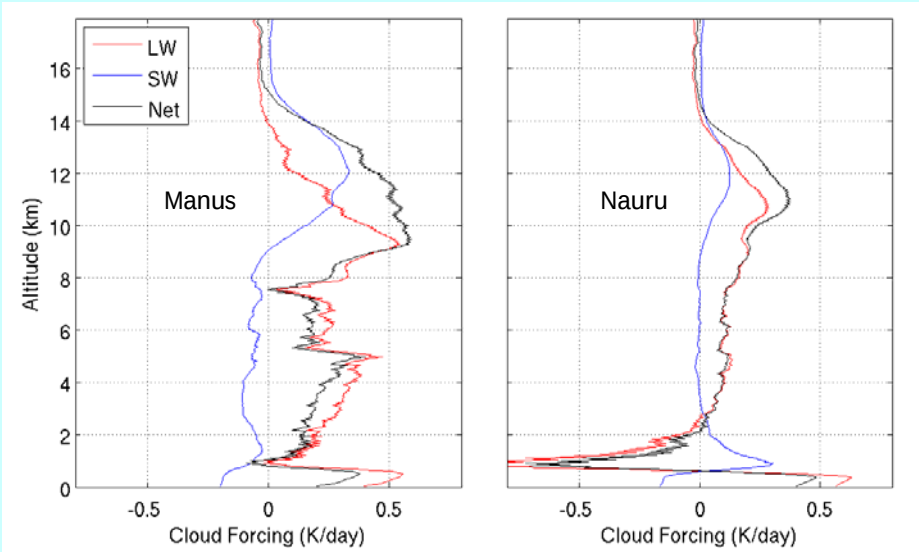
If someone wants to see the residuals. Here is a table of modeled – observed fluxes. All fluxes are downwelling, not net. TOA fluxes were calculated from 0.3 degree Minnis GMS-5 product. Our biggest problem is in the top of atmosphere SW. We strongly suspect that there is an issue of scene mismatch between satellite fluxes and fluxes calculated from surface-sensed cloud properties.

Cloud Data Availability at the Tropical ARM Sites

Processed: (Cloud/HR)	Manus	March - July 2000
	Nauru	February – December 1999
	Darwin	January – February 2006
Radar data:	Manus (3.8 yr)	July 1999 – September 2000 March 2003 – Feb 2005 Dec 2005 – May 2006
	Nauru (3.8 yr)	January 1999 – June 2000 June 2001 – March 2002 Sept 2003 – Dec 2003 June 2004 – May 2006
	Darwin (1.9 yr)	July 2002 – January 2003 Feb 2005 – May 2006

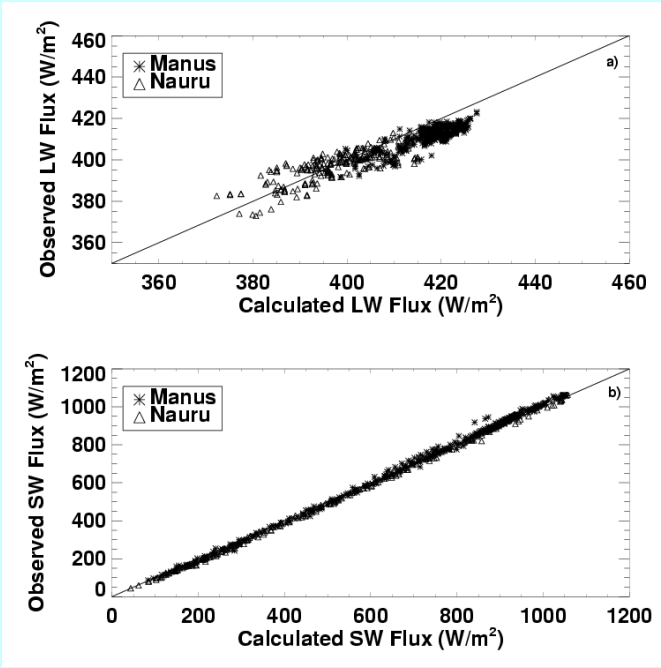
More details on the data. Note – we haven't submitted the darwin data yet. Haven't processed all the tropics data but show here what was available as of this May.

Radiative Heating Rates Due to Clouds



Compare Manus and Nauru cloud effect heating.

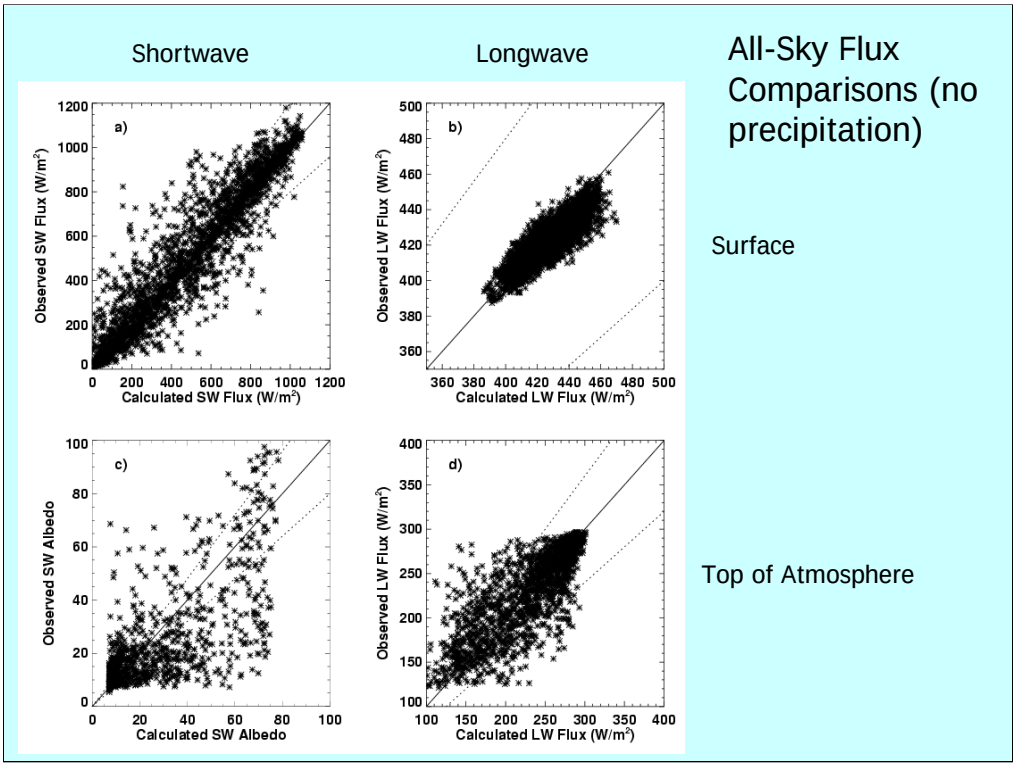
Clear-sky Surface Flux Comparisons



Longwave

Shortwave

Comparison of clear sky surface fluxes for Manus and Nauru – pretty good!



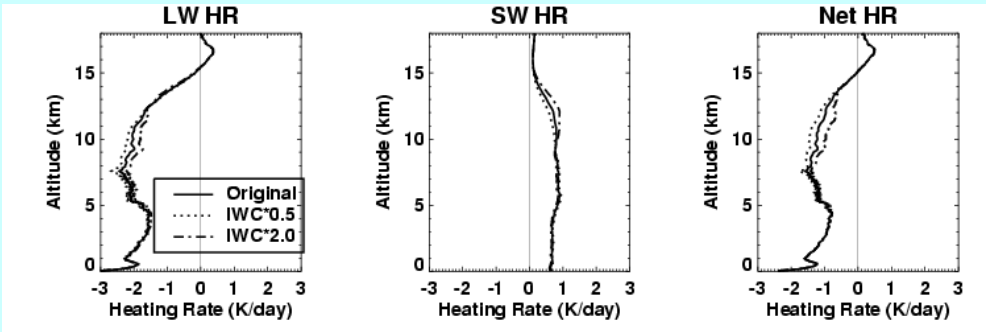
All sky comparison – not as good! But look reasonable (I think) except for TOA shortwave (lower left).

Sensitivity Tests for Calculated Fluxes

Parameter Adjusted	Amount of Change	% Change in LW TOA Flux	% Change in LW Surface Flux	% Change in SW TOA Albedo	% Change in SW Surface Flux
IWC	+100% /-50%	-3.3/2.9	0.1/-0.1	8.3/-6.7	-4.2/3.2
Ice Particle size	+100%/-50%	3.0/-3.1	-0.1/0.1	-8.8/10.8	3.6/-4.5
LWC	+10%(or +20 g/m^2)/ -10% (or -20 g/m^2)	-0.4/0.7	0.6/-0.7	13.0/-11.4	-7.4/5.6
Liquid Particle size	+100%/-50%	0.1/0.0	-0.1/0.0	14.6/-12.2	5.1/-5.9
WaterVapor	+10%/-10%	-0.8/0.8	1.2/-1.4	-0.3/0.3	-0.7/0.7

Sensitivity test where we varied ice water content, liquid water content, particle size and water vapor. Left column shows change in forced parameter while other column show corresponding changes in flux.

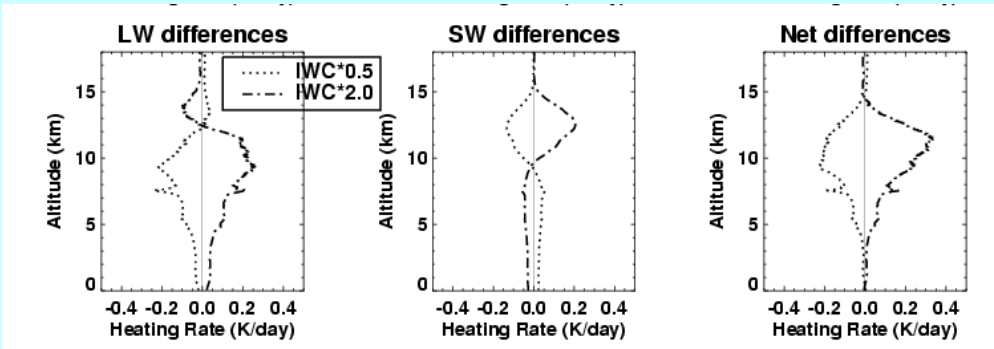
Sensitivity Tests for Ice Water Content



Radiative calculations with the IWC increased by a factor of 2 (*2) and decreased by a factor of 2 (*0.5) relative to best estimate.

Profiles associatied with *2, *0.5 IWC sensitivity tests. Net heating.

Sensitivity Tests for Ice Water Content



Same as previous figure except differences between perturbed profiles and best estimate are shown (perturbed – best estimate).

Cloud forcing associated with the above tests. Show that as you increase IWC – you increase cloud top LW cooling, increase below cloud LW heating, increase in-cloud SW heating and increase below cloud SW cooling. Interestingly, the LW and SW effects ~ cancel below cloud.