Karen Hughes

From: Harald Richter
Sent: Tuesday, 24 July 2012 17:26
To: Alain Protat
Cc: Tom Keenan; Scott Collis; Peter May; Justin Peter; Ken Glasson; Brad Atkinson
Subject: Re: Draft of talk for the Queensland regional office visit [SEC=UNCLASSIFIED]

Alain,

I would present the Darwin work (perhaps quite succinctly), but link it strongly to the benefits that will also affect other regions including the Sunshine State. That way you could merge an enterprise-wide perspective with the immortal WIIFM^ principle.

H

^WIIFM: what's in it for me

Sent from my iPhone

On 24/07/2012, at 5:11 PM, "Alain Protat" <[redacted]> wrote:

> Thanks Tom. It is good to have this framework in mind.
> Yes it was my initial objective to provide an overall view of CAWCR CPOL / CP2 research, as stated in the title, and describe our strategy to extend to broader scales of motion because what we are doing over Darwin and Brisbane (and even regionally and globally) is done to address the same general objectives of better characterizing cloud and convection processes and improve their representation in models. But I also agree with Harald's point that if you want to maximize the impact on the local audience that have local worries, you would tend to show the "local" results.
>
> What I can do is keep the talk similar to what it is, including the regional and global scale aspects, but highlight right from the beginning that the general objectives described are all completely relevant to the global scale, regional scale and in particular the Brisbane area scale.
>
> Would that be OK ? Other thoughts ?
>
> Alain
>
> ---
>
> **From:** Tom Keenan
> **Sent:** Tuesday, 24 July 2012 16:49
> **To:** Alain Protat; Harald Richter; 'Scott Collis'; Peter May; Justin Peter; Ken Glasson; Brad Atkinson
> **Subject:** RE: Draft of talk for the Queensland regional office visit [SEC=UNCLASSIFIED]
>
> <image001.gif>
>
> Alain: Of course the locals will be primarily interested in the local issues. However, part of the purpose here is to inform them of the full scope of our science and not just get focussed on local issues-in fact the reverse-CAWCR needs to have an enterprise perspective on our research. I'm comfortable with you taking a wider perspective. Also remember yours is not the only talk. There will be plenty of other local issues in the topics that come up for discussion, Tom

From: Alain Protat
Sent: Tuesday, 24 July 2012 4:22 PM
To: Harald Richter; 'Scott Collis'; Peter May; Tom Keenan; Justin Peter; Ken Glasson; Brad Atkinson
Subject: RE: Draft of talk for the Queensland regional office visit [SEC=UNCLASSIFIED]

Before I start modifying the talk, I would like to know if everybody agrees that I should focus exclusively on the CP2 radar studies ?

I would then have to change the title of the talk if I do that.

Cheers,

Alain

From: Harald Richter
Sent: Tuesday, 24 July 2012 15:01
To: Alain Protat; 'Scott Collis'; Peter May; Tom Keenan; Justin Peter; Ken Glasson; Brad Atkinson
Subject: RE: Draft of talk for the Queensland regional office visit [SEC=UNCLASSIFIED]

Hi Alain,

What is the specific purpose for the talk in the QLD RFC? I am guessing it might be

(a) to inform the QLD forecasters on selected CAWCR research that utilises DP radars,

(b) to solicit input from the forecasters on what research directions matter to them the most,

(c) to build regional support for the Bureau's DP radar efforts,

(d) to seek research collaborations with selected regional individuals

(e),(f) ...?

Each of the goals above ideally invite a slightly different presentation.

Without knowing the primary goals, I am guessing that your audience in Brisbane will

be more interested in the Gap case than the Darwin work, given the "my backyard"

syndrome. I suspect most attending forecasters will also filter your talk through

'how will my job be affected down the track when the research results flow into

the operational transition pipe?'

Harald

From: Alain Protat
Sent: Tuesday, 24 July 2012 2:37 PM
To: Harald Richter; 'Scott Collis'; Peter May; Tom Keenan; Justin Peter; Ken Glasson; Brad Atkinson
Subject: Draft of talk for the Queensland regional office visit [SEC=UNCLASSIFIED]

Hi everybody,

Here is a draft of the talk I prepared for the visit this friday to the QLDRO. Comments welcome ! Seems long for a 20 minutes talk, but I will go through most of them quickly.

Peter and Tom, can you also tell me if the last slide is in line with the message you want to convey with these meetings ? That's my personal opinion but it may not be something you want to see hlighlighted in individual talks ?

Cheers,

Alain

Alain Protat

Principal Research Scientist

Centre for Australian Weather and Climate Research (CAWCR)

A Partnership between the Australian Bureau of Meteorology and CSIRO

11th floor East

700 Collins Street, Docklands, VIC3008, Melbourne

Tel : [redacted] Fax : [redacted]

Visit my Web Page : http://www.cawcr.gov.au/staff/aprotat/

Karen Hughes

From: Prof. Bringi <[redacted]>
Sent: Wednesday, 6 June 2012 04:22
To: Peter May
Subject: Re: letter for NASA [SEC=UNCLASSIFIED]

Yes, letter is fine. [redacted]

Thanks

Bringi

On 6/4/2012 8:51 PM, Peter May wrote:
> Dear Bringi,
> Does the attached have the correct words?
>
> Regards,
>
> Peter
>
> -----Original Message-----
> From: Prof. Bringi [mailto:[redacted]]
> Sent: Tuesday, 5 June 2012 12:10 PM
> To: Peter May
> Subject: Re: letter for NASA [SEC=UNCLASSIFIED]
>
> Thanks Peter...the full title was in the attached Notice of Intent (I attach it again as it will be the proposal abstract):
>
> "The Application of Dual-Wavelength Ground Radars for Validation of TRMM/GPM Precipitation Algorithms and Related Error Characterization"
>
> Its great that the X-band is fixed and that the pedestal repair work is proceeding.
>
> I don't think I will be at Toronto.. [redacted] but Merhala and Huang will be there.
>
> Regards,
>
> Bringi
>
>
> On 6/4/2012 7:24 PM, Peter May wrote:
>> Dear Bringi,
>> No worries.
>> Re CP2, we have let the contract for the repair work on the pedestal, so that is proceeding and hopefully will be back running in a few months. Ken has also found the gas leak in the X-band so that at least won't continue to be an issue.
>>
>> What is the title of the proposal?
>> Getting some support from it for our work would also be good for us, so we can point to external contracts and agreements we have that are using the facility.
>> You will see we have had some post-docs looking at Darwin storm systems and this may be relevant (you should be hearing from them - we can provide some early drafts of papers if you want). Let me know what we can do to assist with the proposal.

>>
>> For reference, we have the attached paper coming out soon in JClim which analyses C-Pol and cloud radar data among other things. We are interested in extending these sorts of analyses using CP2 data.
>>
>> I think I asked this, but are you going to the Toronto meeting? I will be there, but just for the meeting.
>>
>> Regards,
>>
>> Peter
>>
>>
>> -----Original Message-----
>> From: Prof. Bringi [mailto:[redacted]
>> Sent: Tuesday, 5 June 2012 10:06 AM
>> To: Peter May
>> Subject: Fwd: letter for NASA
>>
>> Yes, I just sent you an email. I am attaching what Kummerow wrote in
>> 2009 as well..you can pattern after that except leave out the NNX
>> number. There are some particular sentences that NASA wants in the
>> letter. More bureaucracy! Let me know if there are problems in
>> getting funds to repair CP2 pedestal. I was able to use data from one
>> event in
>> 2011 that Ken collected for me in the proposal relative to NUBF correction. Will send draft proposal in a few weeks...would appreciate any feedback then.
>>
>> Thanks
>>
>> Bringi
>>
>>
>> -------- Original Message --------
>> Subject: letter for NASA
>> Date: Mon, 04 Jun 2012 16:53:38 -0600
>> From: Prof. Bringi<[redacted]>
>> To: Peter May<[redacted]>
>>
>> Dear Peter:
>>
>> In process of preparing NASA science team proposal. Need a letter
>> from you (scanned pdf is fine) that you are collaborator. The letter
>> from
>> 2009 is attached as well as the Notice of Intent. Please let me know
>> if Nov 2012 is target date for Cp2 to get back on line. Most of my
>> proposal deals with continuation of CP2 work, but adds in SPOLKa
>> during DYNAMO and CHILL/SPOL for front range GPM work.
>>
>> Deadline is 29 June but I aim to submit before 20th.
>>
>> Thanks
>>
>> Bringi
>>
>>
>
> --

> V.N Bringi
> Dept of ECE-1373
> CSU, Fort Collins CO 80523
> office: [redacted]
> fax: [redacted]

--
V.N Bringi
Dept of ECE-1373
CSU, Fort Collins CO 80523
office: [redacted]
fax: [redacted]

Karen Hughes

From: Prof. Bringi <[redacted]>
Sent: Tuesday, 5 June 2012 10:06
To: Peter May
Subject: Fwd: letter for NASA
Attachments: NOI_NSPIRES_2012.docx; Bringi support letter_from_Peter_ Aug 7.doc; kummerow_ltr.pdf

Yes, I just sent you an email. I am attaching what Kummerow wrote in 2009 as well..you can pattern after that except leave out the NNX number. There are some particular sentences that NASA wants in the letter. More bureaucracy! Let me know if there are problems in getting funds to repair CP2 pedestal. I was able to use data from one event in 2011 that Ken collected for me in the proposal relative to NUBF correction. Will send draft proposal in a few weeks...would appreciate any feedback then.

Thanks

Bringi

-------- Original Message --------
Subject: letter for NASA
Date: Mon, 04 Jun 2012 16:53:38 -0600
From: Prof. Bringi <[redacted]>
To: Peter May <[redacted]>

Dear Peter:

In process of preparing NASA science team proposal. Need a letter from you (scanned pdf is fine) that you are collaborator. The letter from 2009 is attached as well as the Notice of Intent. Please let me know if Nov 2012 is target date for Cp2 to get back on line. Most of my proposal deals with continuation of CP2 work, but adds in SPOLKa during DYNAMO and CHILL/SPOL for front range GPM work.

Deadline is 29 June but I aim to submit before 20th.

Thanks

Bringi

--
V.N Bringi
Dept of ECE-1373
CSU, Fort Collins CO 80523
office: [redacted]
fax: [redacted]

Short Title: Dual-wavelength Ground Radars for Algorithm Validation

Full Title: The Application of Dual-Wavelength Ground Radars for Validation of TRMM/GPM Precipitation Algorithms and Related Error Characterization

Brief Description

The proposed work falls into the research category of "Algorithm/Product Validation and Enhancement". In particular, our focus is on specific topics that will seek to improve satellite-based radar (PR-DPR) and combined radar/radiometer (PR-TMI; DPR-GMI) precipitation algorithms including evaluation of DSD and R retrievals, their spatial correlations and NUBF correction. The ground radars we propose to use are dual-wavelength radars such as the CP-2 (S/X-bands) near Brisbane, SPOLKa (S/K_a-bands) operated by NCAR and used for the DYNAMO experiment, and CSU-CHILL (S/X-bands) operated by Colorado State University. These high quality research radars not only allow for S-band polarimetric retrieval of DSD and R, but also their spatial correlation, and furthermore the measure of absolute attenuation at X-band (fairly close to TRMM/DPR K_u-band) in the case of CP-2 and CSU-CHILL, and attenuation at K_a-band in case of SPOLKa. The vertical profile of attenuation, especially in the important mixed phase region of convective storms, will be obtained and used for validation of PIA from TRMM-PR using detailed comparison with satellite overpasses near Brisbane and near Maldives (SPOLKa in DYNAMO). The variation of D_0 with R from ground radar will be compared with corresponding variation from TRMM-PR especially in moderate-to-heavy rain events over land and coastal "ocean" (Brisbane overpasses) and "open" ocean (overpasses over Maldives during DYNAMO). The important NUBF correction methodology will be evaluated by deriving radar-based spatial correlation functions of polarimetric-based R (and attenuation from dual-wavelength data) at sub-PR pixel resolution. The corresponding spatial correlation functions using polarimetric-based retrievals of DSD parameters (median volume diameter, normalized intercept) will be important for satellite algorithm developers as constraints on the expected spatial variability of the DSD and R in different regimes. Finally, in preparation for GPM-DPR based algorithms, we propose to obtain mid-latitude precipitation data from CSU-CHILL and SPOLKa in the Front Range of Colorado (the 2 radars will have a NS baseline of 60 km or so). This unique configuration will provide for simultaneous estimation of attenuation at X and K_a-bands for storms near the center of the baseline. Such data, along with S-band retrievals of DSD and R, will provide for an assessment of DPR-based differential attenuation, its vertical profile and relation to both absolute attenuation as well as to hydrometeor phase state, and to variation with rain intensity.

PI: Professor V.N Bringi, Colorado State University

Co-PI: Gwo-Jong Huang, Colorado State University

Collaborators: Professor Christian Kummerow, Colorado State University

Dr. Peter May, Centre for Australian Weather and Climate Research

Dr. J. Vivekanandan, National Center for Atmospheric Research

Document 7B

The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

Australian Government
Bureau of Meteorology

CSIRO

Prof V.N. Bringi,
Colorado State University,

Dear Prof Bringi,

I acknowledge that I am identified as a collaborator for the proposal “"The dual-wavelength, dual-polarized CP2 radar: Impact of rain and mixed phase precipitation on PR and combined PR/TMI algorithms with potential application to GPM". I intend to participate in this activity and will provide some support for your visits to the CP2 facility and for collaborative activities in Melbourne. This activity is also consistent with our TRMM GV activities. I understand that the extent and justification for my participation in the project will be considered as part of the peer review.

Yours sincerely,

Dr Peter May
Atmosphere and Land Observation and Assessment Research Program Leader
Centre for Australian Weather and Climate Research -
A Partnership between the Australian Bureau of Meteorology and CSIRO

Colorado State University
Department of Atmospheric Science

1371 Campus Delivery
Fort Collins, Colorado 80523-1371
(970) 491-8360
FAX: (970) 491-8449
www.atmos.colostate.edu

August 7, 2009

Prof. V.N Bringi
Department of Electrical and Computer Engineering
Colorado State University
Fort Collins, CO 80523

Dear Prof. Bringi:

I acknowledge that I am identified by name as collaborator to the investigation, entitled "The dual-wavelength, dual-polarized CP2 radar: Impact of rain and mixed phase precipitation on PR and combined PR/TMI algorithms with potential application to GPM" that was submitted by V.N. Bringi to the NASA Research Announcement NNH09ZDA001N-PRECIP, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal. I agree that the proposal correctly describes my commitment to the proposed investigation.

Sincerely,

Christian Kummerow
Professor

Karen Hughes

From: Prof. Bringi <[redacted]>
Sent: Tuesday, 19 June 2012 09:55
To: Vivek; Peter May; Chris Kummerow; gh222106
Subject: NASA proposal
Attachments: Cover_page_plus_abstract.docx; Trmm_proposal_2012_draft_17_June.docx

Dear Collaborators:

Attached is my NASA proposal..if you can take look at it that would be valuable...or point out any glaring errors.
Right now it is exactly at
15 page limit. References not done yet.

Separately is the cover page/abstract.

deadline is end of month but I'd like to upload well before that say 25th.

I understand if you don't have time to read it...a quick scan would do.

Thanks

Bringi

--
V.N Bringi
Dept of ECE-1373
CSU, Fort Collins CO 80523
office: [redacted]
fax: [redacted]

The Application of Dual-Wavelength Ground Radars for Validation of TRMM/GPM Precipitation Algorithms and Related Error Characterization

Submission Due Date: 29 June 2012

Research Announcement: NNH12ZDA001N-PMM

NASA Point of Contact: Dr. Ramesh Kakar
Earth Science Division, Science Mission Directorate
National Aeronautics and Space Administration
Washington, DC 20546-0001
Telephone: [redacted]

Principal Investigator: Prof. V. N. Bringi
Colorado State University
Dept. of Electrical and Computer Engineering
Campus Mail 1373
Fort Collins, CO 80523-1373
Telephone: [redacted]

Collaborators: Prof. C. Kummerow, Colorado State University
Dr. P. May, Centre for Australian Climate and Weather Res.
Dr. J Vivekanandan, NCAR

Budget Summary: Years 1 / 2 / 3: $TBDk / $TBDk / $TBDk
Total for 3 years: $TBDk

ABSTRACT

The proposed work falls into the research category of "Algorithm/Product Validation and Enhancement". In particular, our focus is on specific topics that will seek to improve satellite-based radar (PR-DPR) and combined radar/radiometer (PR-TMI; DPR-GMI) precipitation algorithms including evaluation of DSD and R retrievals, their spatial correlations and NUBF correction. The ground radars we propose to use are dual-wavelength radars such as the CP-2 (S/X-bands) near Brisbane, SPOLKa (S/K_a-bands) operated by NCAR and used for the DYNAMO experiment, and CSU-CHILL (S/X-bands) operated by Colorado State University. These high quality research radars not only allow for S-band polarimetric retrieval of DSD and R, but also their spatial correlation, and furthermore the measure of absolute attenuation at X-band (fairly close to TRMM/DPR K_u-band) in the case of CP-2 and CSU-CHILL, and attenuation at K_a-band in case of SPOLKa. The vertical profile of attenuation, especially in the important mixed phase region of convective storms, will be obtained and used for validation of PIA from TRMM-PR using detailed comparison with satellite overpasses near Brisbane and near Maldives (SPOLKa in DYNAMO). The variation of D_0 with R from ground radar will be compared with corresponding variation from TRMM-PR, especially in moderate-to-heavy rain events over land and coastal "ocean" (Brisbane overpasses) and "open" ocean (overpasses over Maldives during DYNAMO). The important NUBF correction methodology will be evaluated by deriving radar-based spatial correlation functions of polarimetric-based R (and attenuation from dual-wavelength data) at sub-PR pixel resolution. The corresponding spatial correlation functions using polarimetric-based retrievals of DSD parameters (median volume diameter, normalized intercept) will be important for satellite algorithm developers as constraints on the expected spatial variability of the DSD and R in different regimes. Finally, in preparation for GPM-DPR based algorithms, we propose to obtain mid-latitude precipitation data from CSU-CHILL and SPOLKa in the Front Range of Colorado (the 2 radars will have a N-S baseline of 60 km or so). This unique configuration will provide for simultaneous estimation of attenuation at X and K_a-bands for storms near the center of the baseline. Such data, along with S-band retrievals of DSD and R, will provide for an assessment of DPR-based differential attenuation, its vertical profile and relation to both absolute attenuation as well as to hydrometeor phase state, and to variation with rain intensity.

1. Introduction

This proposal is based on the use of ground validation radars possessing both polarimetric and dual-λ measurement capabilities (with one wavelength being non-attenuating i.e., S-band) and the other attenuating (X- or K_a-bands) for satellite algorithm/product evaluation and enhancement (for both TRMM-PR and future GPM-DPR). To the best of our knowledge there are only 3 research radars that have such capability, (i) CP-2 radar located in Brisbane, (ii) SPOLKa deployed in the Maldives (Addu Atoll) for DYNAMO but its home base being central to the Colorado Front Range Observational Testbed (FRONT; Hubbert et al. 2012), and (iii) the CSU-CHILL radar, also central to FRONT.

The ability to retrieve from ground radars the DSD parameters (D_0 and N_W), rain rate (R) and specific attenuation (*k*) at X-band (from CP-2 and CHILL) and at K_a-band (from SPOLKa) offers unprecedented opportunities for ground validation that go well beyond comparisons of Z_e or rain rate from TRMM-PR. Further, such ground radar retrievals set the stage for future GPM-DPR algorithm validation and possible enhancements. While we are aware of the WSR-88D radar system-wide upgrade to dual-polarization and their potential use in TRMM-PR (and future GPM) validation in a much larger scale than possible so far (Wen et al. 2011), the three research radars we propose to use have the significant advantage of being able to estimate the attenuation (close to PR/DPR frequencies) not only in rain but also in mixed phase precipitation. Having an un-attenuated S-band beam is vital to estimate the PIA and its vertical profile and goes well-beyond the measurements of differential attenuation by higher frequency dual-λ ground radars such as D3R (K_u/K_a-bands). The CP-2/SPOLKa/CHILL radars also offer flexible scans with good temporal resolution needed to estimate the spatial correlation functions of DSD parameters, R and specific attenuation in convective storms (scan repeat times of 30-60 s or better). We have already used the NPOL (S-band) radar during MC3E to estimate such spatial correlations (excluding attenuation field) at sub-(PR/DPR)-pixel scales.

In our prior grant cycle, our focus was on TRMM-PR overpasses near Brisbane, AU which is home to the CP-2 radar. A significant number of coordinated cases with CP-2 and TRMM overpass data both in oceanic (rapidly developing east coast lows) and continental storms were available in 2008; however, one problem that was encountered with the CP-2 X-band system was frequent waveguide pressurization loss due to leakage of SF_6. Since the X-band data was vital for our objectives, many of the TRMM overpass events could not be analyzed because the X-band system was down. However, we were able to complete analysis of two good case studies of TRMM overpasses within range of the CP-2 radar during the 2008 rainy season. Second, the antenna pedestal was down starting in March 2009 and the system was up only in October 2011 when the S-band antenna was replaced with a much higher quality antenna previously used on the CSU-CHILL (from 1994 to 2008). The X-band waveguide pressurization problem has now been fixed and the radar is expected to be fully operational in time for the 2012 rainy season.

Because of CP-2 down time we focused our attention on TRMM overpasses over Kwajalein Atoll with the KPOL ground validation radar. Two excellent events over "open" ocean were available for analysis and recently reported on by Bringi et al. (2012). This paper also includes results from the combined PR-TMI optimal estimation scheme of Munchak and Kummerow (2011).

The three main objectives of this proposal are:

- Evaluation of the PR-2A25 V7 products using TRMM overpasses within range of research quality polarimetric/dual-λ ground radars (specifically the CP-2 in Brisbane and SPOLKa during DYNAMO).

- Estimate the spatial correlation function of DSD parameters, R and k at "fine" resolution, i.e., at sub-PR/DPR pixel resolution.

- For future GPM-DPR application, obtain data in mid-latitude precipitation using the CSU-CHILL and SPOLKa radars as part of the Colorado Front Range Observational Testbed (FRONT).

The above objectives are responsive to the NASA PMM Science Team Research Category 2.1 "Algorithm/Product Validation and Enhancement". Specifically, our objectives address the topic: "Error characterization of satellite rainfall retrievals and/or ground-based measurements to facilitate multisatellite algorithm development and the convergence between satellite and GV rain estimates."

2. Background

2.1 D_0 versus R from TRMM overpasses over ground radar

Kozu et al. (2009) have used PR data to infer the distribution of D_0 (median volume diameter) at various sites and comparing it with surface disdrometers in a statistical manner. They make the inference that the attenuation adjustment factor (henceforth simply referred to as ϵ) represents to some extent a "path-averaged" DSD parameter. In Bringi et al. (2012), two case studies from Kwajalein Atoll were analyzed comparing KPOL ground radar (D_0 and R based on polarimetric variables) against PR-2A25 (V6) data using aligned and matched "pixel" data sets (see Fig. 1 for constant altitude sections of reflectivity).

From the Appendix of Kozu et al. (2009) we compute the D_0 for each resolution volume along the PR slant beam as functions of the 2A25-derived R and ϵ, but modified for Version 7 (Kozu, personal communication). Fig. 2 shows the D_0 vs. R scatter plot from KPOL and PR, each data point representing one pixel in the rain layer (for heights < 3 km). The TRMM overpass event is from 8 September 2008. Overlaid on Fig. 2 are curves of constant ϵ. There is excellent agreement in the variation of D_0 vs. R from Version 7 and KPOL radar (note: Version 6 is also in good agreement except D_0 is biased a bit higher by around 0.25 mm for R> 10 mm/h). The KPOL scatter is within the range of ϵ between 1 and around 1.5, typical of "open" ocean values.

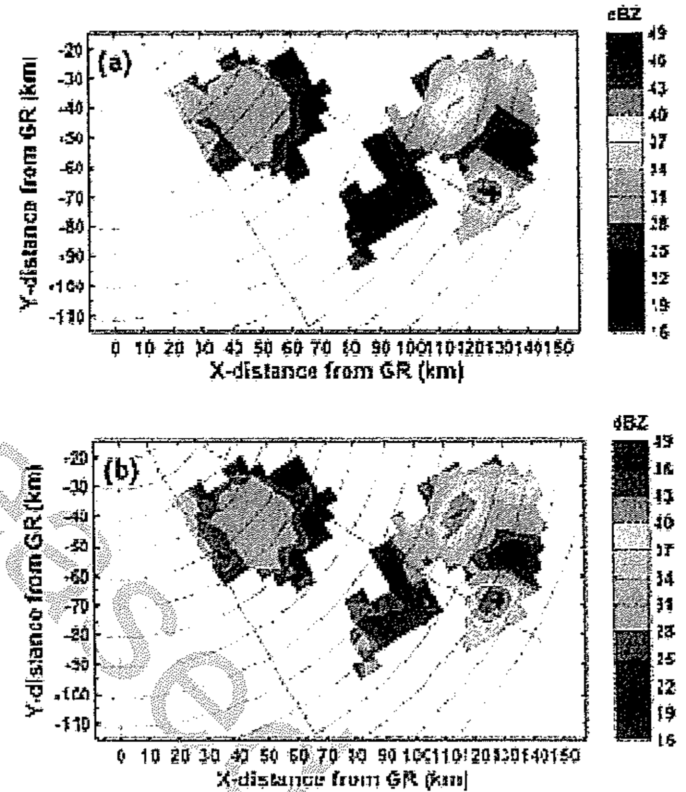

Fig. 1: Constant altitude PPI at 3 km for 8 September overpass, (a) attenuation-corrected PR reflectivity from 2A25, and (b) from KPOL radar. The '+' marks the peak reflectivity. The "pixel" size is 4X4X0.5 km.

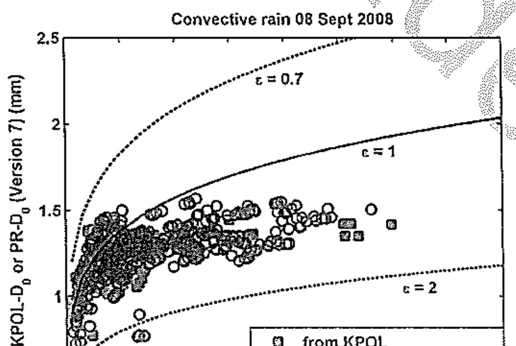

Fig. 2: Scatter-plot of D_0 vs. R from KPOL ground radar and from PR-V7 for the 8 September 2008 TRMM overpass over Kwjalein Atoll. Each data point is from a common pixel of 4X4X0.5 km after alignment and volume matching. Note that D_0 from

KPOL is based on Z_{dr}, while R is based on a composite $R(Z_h, Z_{dr})$ and $R(Z_h)$ algorithm based on Joss disdrometer data.

We have similar comparisons (not shown here) for another event over Kwajalein and one coastal "ocean" case near Brisbane which show good agreement of D_0 vs. R scatter plots from PR-2A25 and ground radar (CP2 radar located near Brisbane). This is a good indication that V7 is performing well over the ocean in so far as the variation of D_0 versus R is concerned. The rain rates themselves typically tend to be systematically lower (more so in V6 than V7) relative to polarimetric ground radar-based values for R> 10 mm/h or so. The fact that V7 performs better than V6 relative to ground radar might be due to re-introduction of the NUBF correction (Iguchi et al. 2009). We note that we can compare the D_0 vs. R variation from PR-2A25 and ground radar in similar rain types without going through the alignment and matching process.

In the one convective land event near Brisbane which we have analyzed in detail, the D_0 vs. R from PR-2A25 (V7) is quite a bit different than that inferred from the CP-2 radar. Fig. 3 shows the constant altitude sections of reflectivity from PR and from CP-2. This event was strongly convective over elevated hilly terrain to the west of Brisbane. The D_0 vs. R scatter plot is shown in Fig. 4 (along with contours of constant ϵ and the 2D-video based bounds). The dramatic increase in PR-D_0 values and the separate "branch" that it follows with R is very different from that inferred by the CP-2 polarimetric retrievals (which fall within the 2D-video disdrometer bounds). Essentially, the ϵ from 2A25 is predicted to be too small giving a large D_0 (big drops) and in turn seriously underestimating the rain rates. This bias in ϵ over land in strong convection is well-known (Iguchi et al. 2009) and might be related to either inaccuracy in the SRT method over land, or NUBF correction or the assumed vertical profile of the k-Z_e relation (inability to account for mixed phase precipitation aloft).

We have also performed a detailed analysis of comparing k from PR and k deduced from the CP-2 dual-λ data (unattenuated beam at S-band and attenuated beam at X-band). After frequency scaling of the CP2-k from X to K_u-band, we find that the k from PR is biased too low relative to that inferred from the CP-2 radar (see Fig. 5 left panel; the right panel compares the rain rates). We are confident of the polarimetric-based rain rates since they are also consistent with R derived from CP-2 k values using a k-R relation derived from 2D-video DSDs (the radar k being unaffected by absolute radar calibration). Further, when we correct the PR-measured reflectivity using PIA from CP-2-radar, the agreement of the corrected reflectivity with the CP-2 measured reflectivity (at S-band but scaled to K_u-band) is much better in the rain layer (not shown here). This also translates into better rain rate comparisons.

We need to analyze more cases for overland convective events within range of the CP-2 radar, but reiterate that the D_0-R variability can be compared with 2A25 in similar convective rain types without the need for alignment and matching. However, we intend to analyze TRMM overpasses as and when they occur near Brisbane for more detailed "pixel" comparisons of k from PR versus k from CP-2 radar (and also the PIA). The combination of D_0-R and k comparisons in variety of convective rain events (continental vs. oceanic, for example) will lead to a better performance evaluation of the V7 algorithm (as an alternative to statistical Z comparisons or R comparisons with gauges).

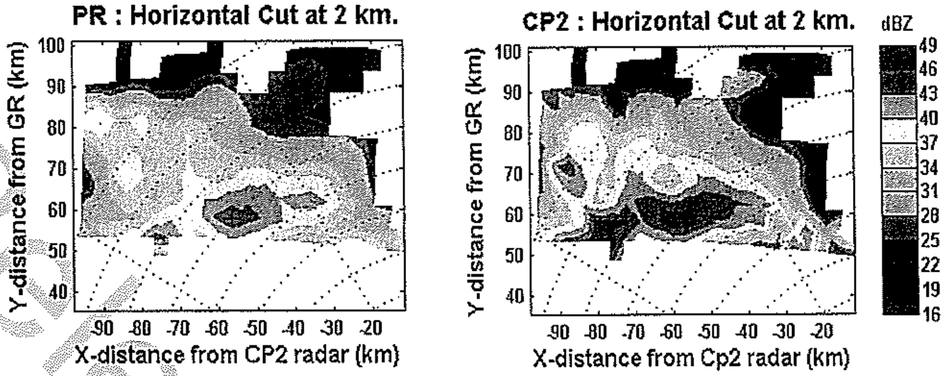

Fig. 3: As in Fig. 1 except for the land case of 5 Nov 2008 near Brisbane and ground radar is the CP-2.

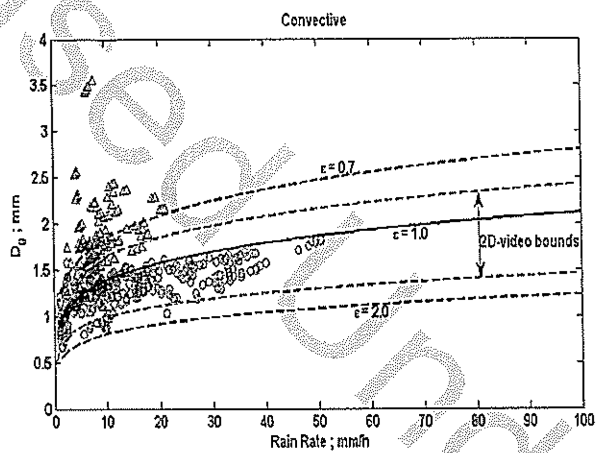

Fig. 4: As in Fig. 2 except for the land case of 5 Nov 2008 near Brisbane.

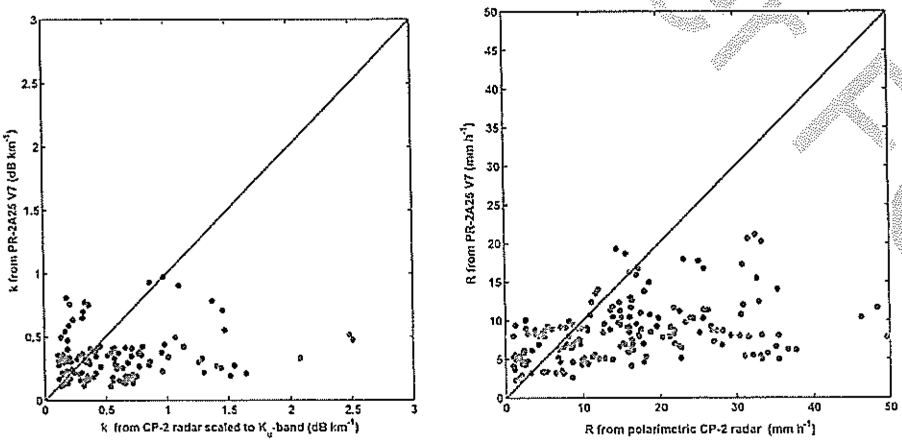

Fig. 5: (left panel) PR-k derived from measured and corrected reflectivity versus that derived from the CP-2 dual-λ radar. Note severe underestimate by PR-2A25 leading to corresponding underestimate in R relative to CP-2 polarimetric radar-based retrieval (right panel).

2.2 Radar-derived spatial correlations

It is well-known that the rain rate exhibits large variability, the extent depending on the spatio-temporal scales of interest. In the context of satellite-based radar (PR or DPR) algorithms, the "pixels" near the surface are around 5X5 km (and the temporal scales are < few mins). Thus, the "sub-pixel" scale variability is particularly important to quantify. Typically dense gauge networks have been used to quantify such variability but it takes a long time to acquire sufficient data to estimate the parameters of the spatial correlation function expressed, for example, in the form $\rho(d)= \rho_0 \exp[-d/R_0]^F$ with high statistical confidence (Habib and Krajewski 2002; Gebremichael and Krajewski 2004). The situation with respect to DSD parameters $[D_0,N_W]$ is even more lacking as dense disdrometer networks are just beginning to be deployed (Jaffrain et al. 2011; during MC3E; more recently at Wallops Island).

Polarimetric radar offers a solution since the pixel size is around 1x1 km for a 1 deg beam at 60 km range and better at shorter ranges, provided the radar sampling time is low (typically < 30-60 s) for convective rain types. In effect, a long time series can be obtained at each pixel and then the Pearson correlation coefficient as a function of range and azimuth can be computed. Such data can then be used to estimate the parameters of the spatial correlation function (decorrelation radius R_0, and shape parameter F). To the best of our knowledge, this was first done by Moreau et al. (2009) using the "ZPHI" method at X-band. More recently, Thurai et al. (2012) used the ARMOR radar to estimate the spatial correlation of D_0, log N_W and R.

In this proposal we are particularly interested in using the CP-2 dual-λ radar to derive the spatial correlation of specific attenuation *k* at X-band for application to NUBF correction methods for PR reflectivity (and rain rate) as described in Iguchi et al. (2009). We have one example of data collected by the CP-2 radar over a sector covering the "coastal" ocean in convective rainfall (PPI scans at 1 deg elevation angle repeated every 30 s for a period of 80 mins). Fig. 6 shows a PPI scan of reflectivity from the event of 8 Dec 2011; note the convective cells appear to be unorganized at least at the mesoscale. Fig. 7 (left panel) shows the spatial correlation function with radial distance from an arbitrary reference point marked by a solid dot in Fig. 6. Also plotted in Fig. 7 is the autocorrelation function derived by Kozu and Iguchi (1999) via a geostatistical approach using a large number of 2-km CAPPIS from the MIT C-band radar in a large variety of convective rain events during TOGA-COARE. They used a Z-R relation to estimate R ($Z=234 R^{1.59}$). While this is only shown here as an illustration, the agreement is quite reasonable [in terms of R_0 and F] considering the completely different methods used to arrive at the spatial correlation function.

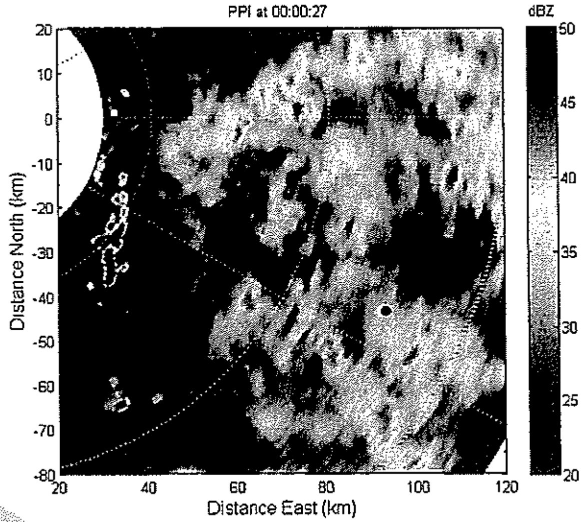

Fig. 6: PPI plot of reflectivity at low elevation angle from CP- radar over ocean on 8 Dec 2011. Such PPI scans were repeated every 30 s for over 80 mins. Black marker "dot" locates the reference pixel from which the spatial correlation function is estimated, i.e., distance is radial and incremented by gate spacing of 150 m.

In Fig. 7 (right panel) we show the spatial correlation function of k at X-band (for the same event) derived using the dual-λ technique to illustrate its behavior. At lower reflectivities (<35 dBZ) the derived k is "noisy" so we use a "tuned" k-Z relationship based on 2D-video data from Brisbane (k= 2.0E-04 $Z^{0.74}$), Z being measured at S-band while k is at X-band. Given the scaling from X to K_u-band, our k-Z relation is not too far from what is used as the default for convective rain type (Iguchi et al. 2009). Note that the decorrelation distance for k is smaller than for R but this is a very preliminary result at this time [R_0 of 4.26 km versus 3.38 km]. One objective of our proposed research is to collect a number of such specialized data sets using the CP-2 radar and obtain the spatial correlation coefficient of D_0, log N_W, R and k in different rain types (e.g., continental and oceanic).

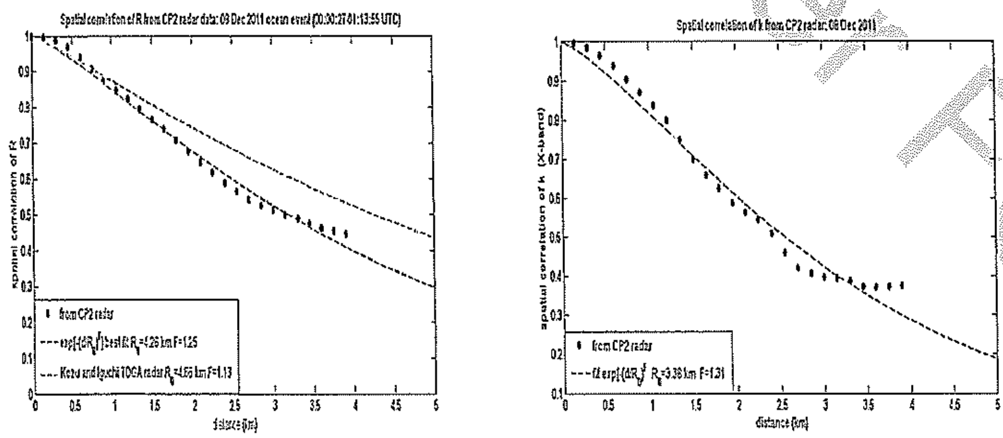

Fig. 7: (left panel) spatial correlation function of R from CP-2 radar. The blue dotted line is from Kozu and Iguchi (1999); (right panel) spatial correlation of k at X-band using dual-λ method with best fit.

We believe that by estimating the spatial correlation function of *k* using the CP-2 dual-λ ground radar in a variety of rain types should yield valuable information to evaluate and possibly improve the NUBF-correction methodology, and in fact is fundamental to any down-scaling methodology. The vertical variability is also important for PR and DPR algorithm developers but is complicated by non-stationarity, for example, variable freezing level height in convection due to up/down drafts and vertical correlations due to fall speeds. But we have made some attempt at estimating the vertical correlation function using high time resolution RHI scans in deep convection from NPOL radar during MC3E (Thurai et al. 2011).

2.3 Attenuation in mixed phase precipitation

In convective storms, especially over land, the precipitation is often a mixture of supercooled rain and graupel/hail in the important mixed phase region typically extending between 5 to -10 C. Depending on the in-cloud conditions, the hail may also be in wet-growth. The freezing level can vary with height due to up/down drafts. Attenuation in the mixed phase region can thus be expected to be highly variable at the PR and DPR frequencies. With DPR it will be possible to detect the top/bottom boundaries of the mixed phase precipitation from rain below and dry ice/snow aloft. The differential attenuation (between the two frequencies) will be measureable up to the range that the K_a-band signal becomes extinct. Hence, the GPM-DPR radar will provide valuable data regarding the vertical structure of the mixed phase precipitation, which for PR is based on an assumed vertical model of the k-Z_e relation (V7 incorporates some important changes relative to V6 as given in Table D1 of Iguchi et al. 2009). While the differential attenuation between frequencies is an important measure, which potentially sets the basis for converting it to PIA at each frequency (at least in rain), the SRT method is likely to play a continuing vital role in estimating the PIA at both frequencies.

The CP-2 data (apart from its use in studies such as shown in Figs. 3-5 and 7) can also be used to study the k-Z_e variability in the mixed phase region of convective storms. As an illustration we show in Fig. 8 the vertical section of S-band Z_e and *k* at X-band in a severe convective storm which occurred on 26 March 2008 near Brisbane. Between the heights of 3.5-6 km is a "pocket" of enhanced *k* values (2.5 dB/km), while below 3.5 km is the main precipitation shaft composed of heavy rain with rates around maximum of 150 mm/h. This storm was scanned repeatedly for more than an hour giving a large number of "pixels" from which to examine the k-Z_e variability (and the power law fit) in the mixed phase region (3.5-6 km) and within the main precipitation shaft.

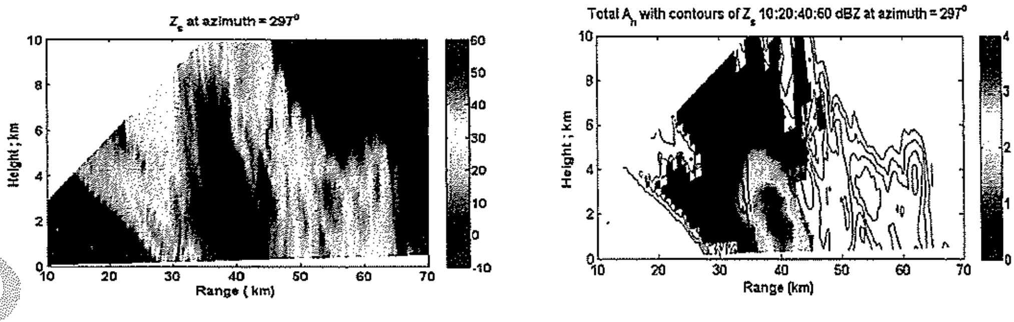

Fig. 8: (left panel) vertical section of Z_h (S-band) through a severe convective storm using CP-2 radar; (right panel) vertical section of k (X-band) using dual-λ method.

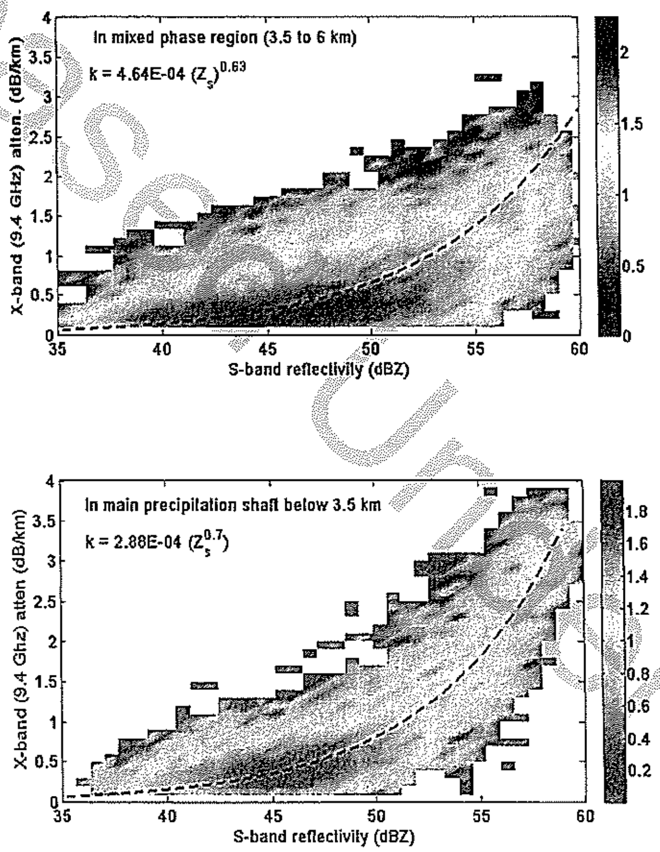

Fig. 9: (top panel) contoured frequency of occurrence (in log scale) plot of k-Z from CP-2 radar data in mixed phase region (pixels between 3.5-6 km in height); (right panel) similar plot except within main precipitation shaft (pixel height< 3.5 km). Also shown is the best fit power law. Note Z is S-band reflectivity (abscissa) while k is at X-band (ordinate).

Fig. 9 (top panel) shows the contoured frequency of occurrence plot of k vs Z_e in the mixed phase region along with the power law fit, k = 4.64E-04 ($Z_e^{0.63}$). Note that Z_e is at S-band and that there is considerable spread from the power law fit. The bottom panel in Fig. 9 shows a similar plot except in the main precipitation shaft (heights < 3.5 km), the power law fit now being k = 2.88E-04 ($Z_e^{0.7}$) with relatively less variability about the fit. The exponent of the power law fit in the mixed phase region is lower than for the main precipitation shaft, as expected. As such the vertical k-Z_e model in 2A25 keeps the exponent the same (at 0.78) but decreases the multiplicative coefficient as temperature decreases. One consequence is that the larger exponent will allocate more of the total attenuation aloft and less so at the surface (depending on Z_e of course). As illustrated in Fig. 5, we have been able to use k from CP-2 radar (scale it to K_u-band) and then correct the measured PR-Z_e for attenuation, so this procedure automatically accounts for different attenuation in the mixed phase region versus the rain below. While. so far, we have done this for only two TRMM overpasses near Brisbane, our proposed work plan will continue such an approach (along with D_0 vs. R comparisons and spatial correlation analysis) to determine which of the 2A25 algorithm assumptions are probably causing the systematic underestimate in R for convective events over land (i.e., NUBF-correction, vertical k-Z_e model or PIA estimation from SRT method).

2.4 Attenuation at K_a-band

The SPOLKa radar offers a direct estimation of the specific attenuation at K_a-band since there is always the reference S-band beam (e.g., Ellis and Vivekanandan 2011). [http://www.eol.ucar.edu/instrumentation/remote-sensing/s-pol/s-pol]. In addition, with the polarimetric variables available at S-band, the SPOLKa radar offers a unique platform for evaluation of K_a-band attenuation and its vertical profile for DPR algorithm application. In particular, the deployment of SPOLKa in the Maldives (Addu Atoll) for DYNAMO (Dynamics of the Madden-Julian Oscillation: 1 Oct 2011- 15 Jan 2012) is of interest in our proposal for DSD, R and K_a-band attenuation retrieval during TRMM overpasses within range of the SPOLKa radar. We have determined that at least one excellent TRMM overpass occurred on 08 Dec 2011, as well as numerous overpasses by the Megha-Tropiques satellite (we intend to informally collaborate with Drs. Haddad and Turk of JPL by coordinating our SPOLKa retrievals of DSD, R and K_a-band specific attenuation with their work related to analysis of Megha-Tropiques data). Our formal collaborator with respect to SPOLKa radar is Dr. J. Vivekanandan of NCAR who will pursue earlier studies on water vapor retrieval as well as liquid water content estimates using SPOLKa (Ellis and Vivekanandan 2010; Ellis and Vivekanandan 2011) which is of relevance to our proposed work as well.

We illustrate here the retrieval of K_a-band specific attenuation using the software already developed for the CP-2 radar (to retrieve k at X-band) with minimal tuning. Fig. 10 shows a low elevation angle PPI sector of S-band reflectivity to set the context. The white arrow depicts the azimuth angle along which RHI scans were performed at 10:20 UTC. Fig. 11 (left panel) shows the vertical section of S-band reflectivity; note the cell tops barely penetrate above the 0 C height (around 5 km), with most intense reflectivity below 4 km height. Fig. 11 (right panel) shows the retrieved K_a-band specific attenuation (k_a) using the dual-λ method. Note the "pocket" of enhanced k_a at range of 22 km and height of 2.5 km (peak around 3.5 dB/km). Not surprisingly, the K_a-band signal is extinct past 25 km range. However, when viewed by DPR from above the K_a-band signal would likely be able to penetrate the cell. Such DPR scenarios can be simulated with SPOLKa polarimetric/dual-λ based retrieval techniques which is within our scope of work.

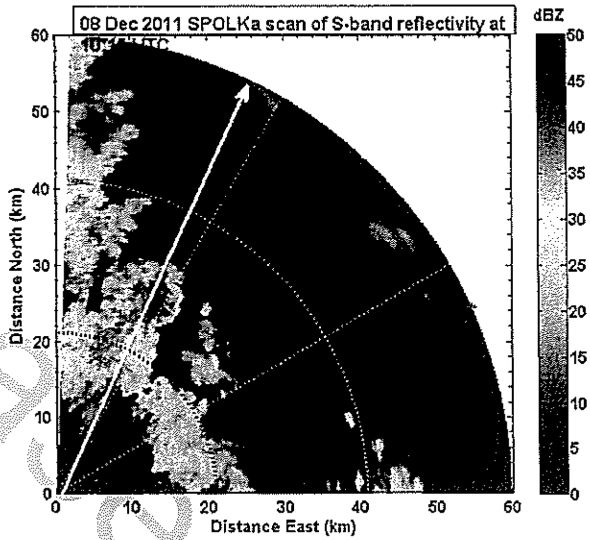

Fig. 10: Sector PPI data of S-band reflectivity from SPOLKa on 08 Dec 2011 event at 10:15 UTC during the DYNAMO project. Range rings are 20 km apart. The white arrow is the azimuth along which the K_a-band specific attenuation is retrieved (from RHI data at 10:20 UTC).

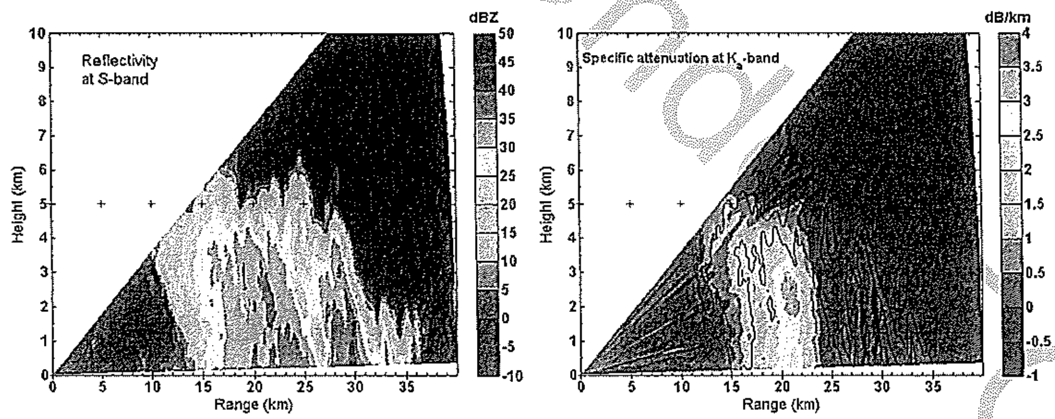

Fig. 11: RHI along azimuth angle marked by arrow in Fig. 10: (left panel) S-band reflectivity, and (right panel) K_a-band specific attenuation with contours of S-band Z overlaid (contours start at 20 dBZ with increment of 10 dB). Note "pocket" of enhanced attenuation at range= 22 km and height= 2.5 km. Also, K_a-band signal falls below noise level past range of 24 km in this particular RHI.

Finally, Fig. 12 demonstrates that our retrieval of K_a-band specific attenuation (k_a) from SPOLKa is quite accurate in rain. The contoured frequency of occurrence (in log scale) of k_a vs Z_e is shown in color from the same PPI scan in Fig. 10. The overlay in grey circles is from simulations from Joss DSDs (1-min average) from Kwajalein Atoll. Note the good agreement between SPOLKa-derived variation and that from simulations. We intend to analyze 2D-video disdrometer from DYNAMO (operated by DOE) to simulate K_a-band attenuation versus R, but also develop "tuned" retrieval algorithms for DSD parameters [D_0, N_w] and R from S-band polarimetric variables. The results in Fig. 12 gives us confidence in our retrievals of K_a-band attenuation using the S-band as reference beam through the mixed phase region which is within our scope of work and of importance to DPR algorithms.

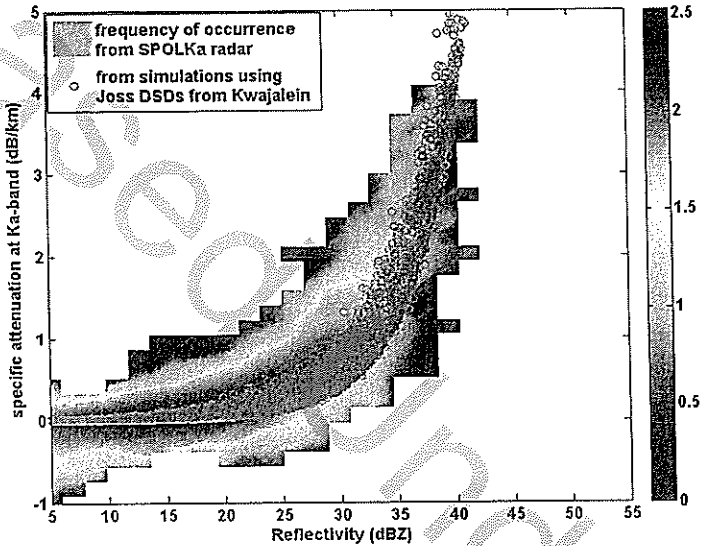

Fig. 12: Contoured frequency of occurrence of K_a-band specific attenuation versus Z_e from SPOLKa radar (data from PPI scan in Fig. 10). Frequency of occurrence in log scale (see color bar). Overlay of grey points is from simulations using Joss 1-min DSDs from Kwajalein Atoll.

3. Research Objectives

From the PMM-NRA document we identify our research as targeting the area related to, "Algorithm/Product Validation and Enhancement". In particular, our focus is on specific topics that will seek to improve satellite-based radar (PR-DPR) and combined radar/radiometer (PR-TMI; DPR-GMI) precipitation algorithms including evaluation of DSD and R retrievals, their spatial correlations and NUBF-correction.

(i) Evaluate PR-2A25 products (on a case study basis) with regard to PIA, D_0=f(R,ϵ), R, vertical profile of k and NUBF-correction using TRMM overpasses within range of research quality polarimetric/dual-λ ground radars (specifically the CP-2 and SPOLKa radars). Extend to evaluation of K_a-band attenuation and its vertical profile along with DSD parameters and R from SPOLKa during DYNAMO (includes TRMM overpass targets of opportunity as well as collaboration with Megha-Tropiques investigators).

(ii) Estimate the spatial correlation function of DSD parameters, R and *k* at "fine" resolution, i.e., at sub-PR/DPR pixel resolution, in a variety of rain types using the CP-2 radar.

(iii) Evaluate DPR-based differential attenuation methods in mid-latitude precipitation using the CSU-CHILL and SPOLKa radars (coordinated estimation of specific attenuation at X and K_a-bands) as part of the Colorado Front Range Observational Testbed (FRONT). Includes spatial correlation function estimation of DSD, R and specific attenuation at X and K_a-bands. Includes summer and winter precipitation events (targets of opportunity).

4. Data Sources

We list below the data sources needed to achieve the above objectives:

(i) The CP-2 polarimetric/dual-λ radar located near Brisbane operated by the Australian Centre for Climate and Weather Research. This radar measures polarimetric variables at S-band and Z_e at X-band, allowing for the estimation of the specific attenuation. The dual-λ beams are matched with 3-dB beam widths of 1°.

(ii) The SPOLKa radar located in the Maldives (Gan) for DYNAMO. This radar is operated by NCAR as a national facility. It measures polarimetric variables at S-band and Z_e at K_a-band, allowing for the estimation of the specific attenuation. The dual-λ beams are matched with 3-dB beam widths of 1°.

(iii) Data collected simultaneously by CSU-CHILL and SPOLKa radars as part of the Front Range Observational Network Testbed. The CSU-CHILL radar is operated by Colorado State University as a national facility. Dual-λ (S/X-bands) measurements are made with a common dual-λ feed illuminating a dual-offset Gregorian antenna (perfectly matched bore sight). It measures polarimetric variables at S-band with 1° beam and same at X-band except with 0.33° beam. The X-band specific attenuation can also be estimated.

5. Work Plan

Our work plan described below follows the itemized list of objectives in Section 3.

Year 1:

(i) Select suitable TRMM overpasses within range of CP-2 during the 2012-2013 rainy season (in continental and oceanic squalls), and continue our evaluation of 2A25 products as described in Section 2.1. Also, focus on attenuation in mixed phase precipitation as described in Section 2.3.

Start with selecting one TRMM overpass event during DYNAMO that occurred within 75 km range from SPOLKa (excellent event occurring on 8 Dec 2011). Obtain SPOLKa data and fine-tune algorithms to estimate specific attenuation at K_a-band, as well as develop polarimetric-based retrieval algorithms for D_0 and R from 2D-video disdrometer data collected during DYNAMO (operated by DOE).

(ii) Collect high time resolution PPI data sets using CP-2 radar during long duration rain events (<60 s PPI repeat time) to estimate the spatial correlation function of DSD parameters, R and *k* as described in Section 2.2.

(iii) In anticipation of FRONT campaign in summer of 2013, collect specialized data sets using the CSU-CHILL radar with dual-λ feed during July-August 2012 both for vertical profiling of specific attenuation at X-band as well as for estimating the spatial correlation function.

Prepare for presentations at PMM science meeting (TBD) and for the AMS Radar Meteorology Conference to be held in Tsukuba, Japan in Fall 2013.

Year 2:

(i) Complete analysis of TRMM overpass events coordinated with CP-2 radar. In collaboration with PR (and DPR) algorithm developers and from the detailed case study analysis, determine which of the 2A25 algorithm assumptions are most responsible for bias in R for convective events over land.

Continue analysis of the TRMM overpass event coordinated with SPOLKa radar using methods already developed in Year 1. Focus on the vertical profile of K_a-band specific attenuation in rain and mixed phase region, as well as DSD and R retrievals. Compare with retrievals from Megha-Tropiques for the same event via collaboration.

(ii) Evaluate NUBF-correction methods using the CP-2 radar-derived spatial correlation functions.

(iii) Continue analysis of CSU-CHILL data collected in Year 1. During summer of 2013 the CSU-CHILL and SPOLKa radars will be central for the FRONT-Precipitation Observations and Research on Convection and Hydrometeorology campaign. Use this opportunity to collect data sets from both radars (base line 50 km) for estimating specific attenuation at X and K_a-bands on storms about equi-distant from both radars (targets of opportunity).

If GPM launch proceeds on schedule it would occur mid-way through the 2^{nd} year. Seek ways to transfer our 2^{nd} year results to DPR and combined DPR-GMI algorithm developers, especially differential attenuation vs. absolute attenuation and spatial correlation function of DSD parameters, R and *k* (range of the fitted values that can be expected in the mid-latitudes). Prepare presentation for GPM-GV meeting (TBD) and other conferences such as EGU or TGARS. Submit several manuscripts for publication with our collaborators.

Year 3:

(i) Complete the CP-2 and SPOLKa analyses as described in years 1 and 2. Evaluate the impacts of our findings relative to DPR data expected to be available to researchers involved in GV.

(ii) Complete the radar-based spatial correlation analysis using CP-2 and CSU-CHILL data. Determine the variability of the fitted parameters [decorrelation radius and function shape] with rain types and whether over land or coastal "ocean" (latter only for Brisbane).

(iii) Complete the analysis of data described in Year 2. In particular, evaluate differential attenuation in rain and mixed phase regions in conjunction with polarimetric-retrievals of DSD parameters and R from both radars.

Prepare presentation for PMM Science meeting (TBD). Prepare presentations for at least one conference with special session on GPM. Submit for publication several comprehensive manuscript synthesizing our findings.

6. Personnel, Collaboration and Budget Explanation

A 3-year research effort is proposed with Prof V.N. Bringi as PI at 1 mo effort each year. Prof. Bringi will retire as faculty on 31 Dec 2012 but re-join CSU as Senior Research Scientist (1/2 time of a 9-month appointment). Dr. Gwo-Jong Huang will be full-time (12 mos each year) as Research Scientist/Scholar on the project. Our principal collaborators will be Prof. Kummerow of Colorado State University, Dr. J. Vivekanandan of NCAR, and Dr. Peter May of the Centre for Australian Weather and Climate Research in Melbourne, Australia. The latter Centre has a group led by Dr. May for contributing to GV-team related activities in Brisbane and Darwin.

Partial travel funds are requested for Prof. Bringi to spend 10 days in Year 1 at Melbourne/Brisbane for collaboration with Dr. May's group. Travel funds are also requested for Prof. Bringi and Dr. Huang to attend one PMM science/GV meeting each year. Standard publication costs are included in each year to disseminate the knowledge gained from this research.

Liquid water content estimates using simultaneous S and K_a band radar measurements

RADIO SCIENCE, VOL. 46, RS2021, doi:10.1029/2010RS004361, 2011

Scott M. Ellis[1] and Jothiram Vivekanandan[1]

Ellis, S. M., and J. Vivekanandan, 2010: Water vapor estimates using simultaneous dual-wavelength radar observations. Radio Science, 45, RS5002, doi:10.1029/2009RS004280.

FRONT: The Front Range Observational Network Testbed
Room 239 (New Orleans Convention Center)
John C. Hubbert, NCAR, Boulder, CO; and P. C. Kennedy, V. Chandrasekar, S. Rutledge, W. C. Lee, V. Bringi, T. M. Weckwerth, J. Wilson, D. A. Brunkow, M. Dixon, J. George, E. Loew, J. Van Andel, A. Phinney, R. A. Rilling, and S. M. Ellis
92nd Annual AMS Meeting, New Orleans, 22-26 Jan, 2012