Implementing double moment microphysics into the Unified Model

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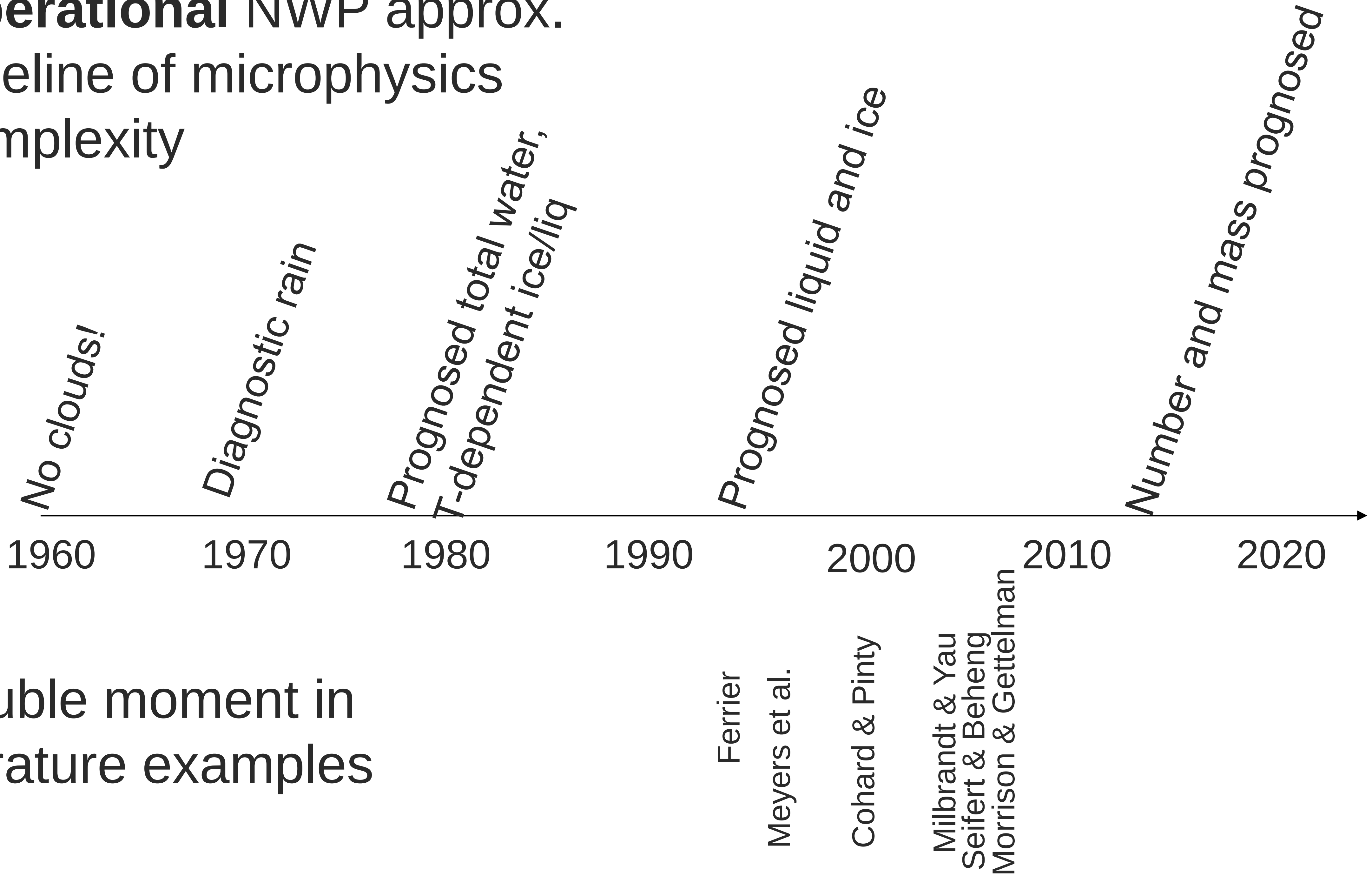
Robin Stevens, Dan Grosvenor,
Kwinten Van Weverberg

Operational NWP approx. timeline of microphysics complexity



Double moment in literature examples

CASIM multi-moment microphysics scheme

5

hydrometeor species

Cloud droplets
Rain
<u>Cloud ice</u>
Snow
Graupel

2

prognostic moments

<u>Number</u>
Mass

[Optional 3rd prognostic]

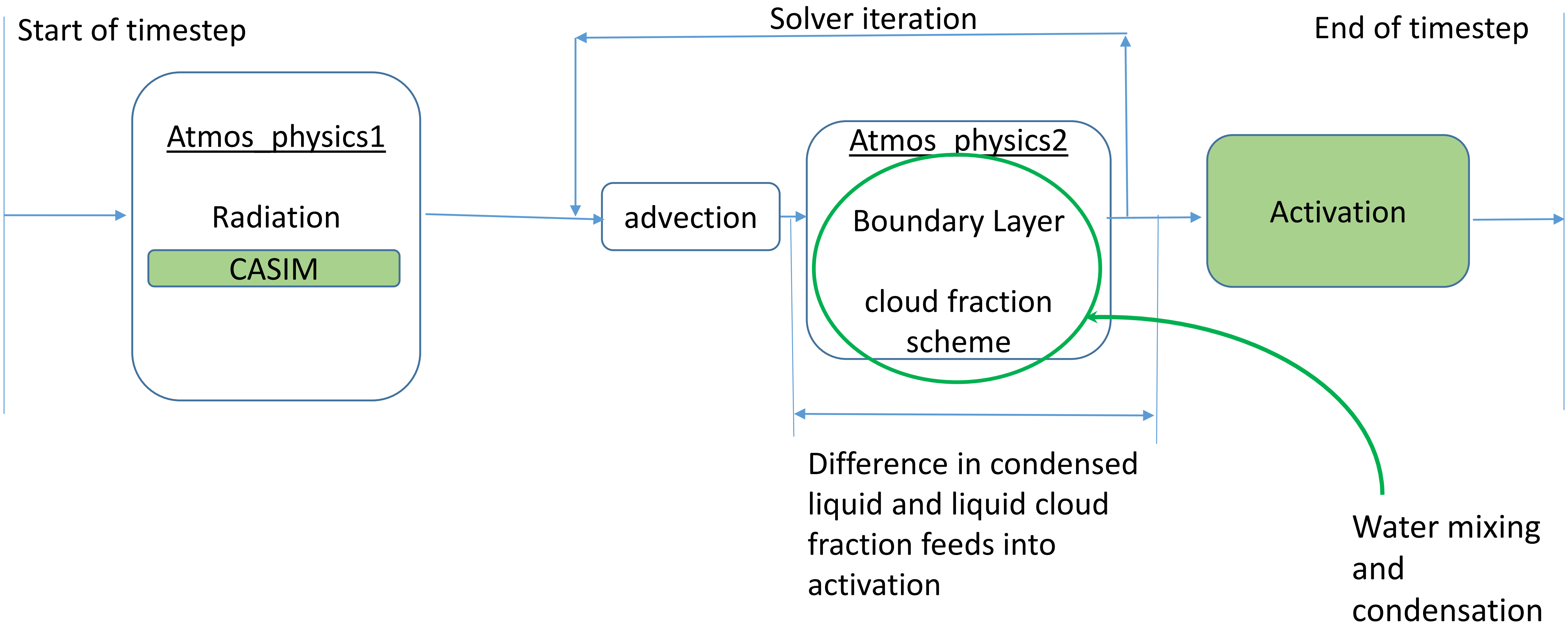
Can be coupled to aerosol to represent CCN and INP.

[UKCA, MURK, ARCL]

[RA3 config uses a prescribed in-cloud number concentration]

Cloud **A**ero**S**ol **I**nteracting **M**icrophysics

CASIM components in UM timestep



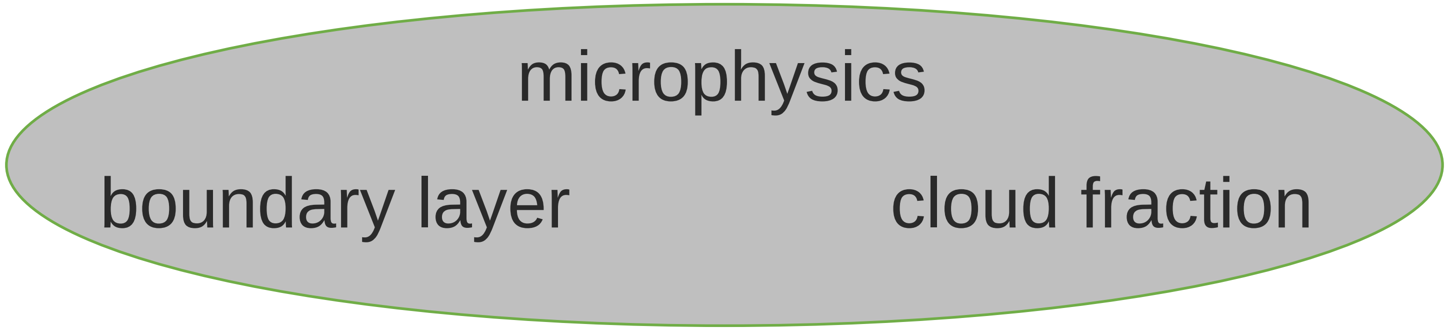
Not just about cloud microphysics …

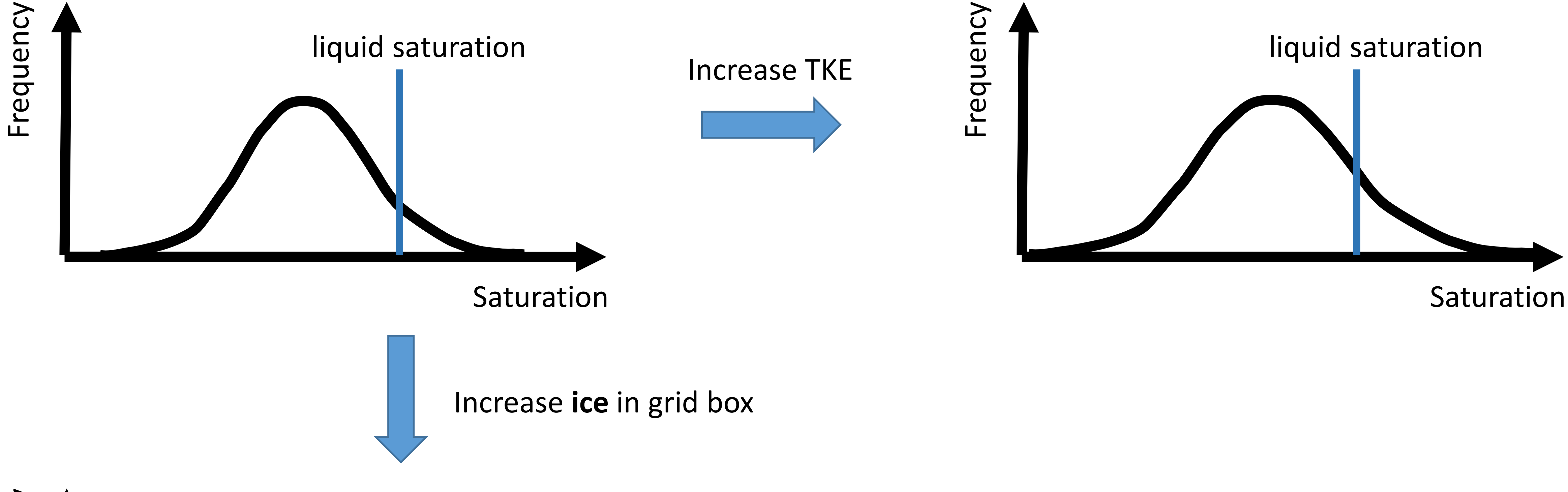
Boundary layer scheme (Lock et al. 2000)

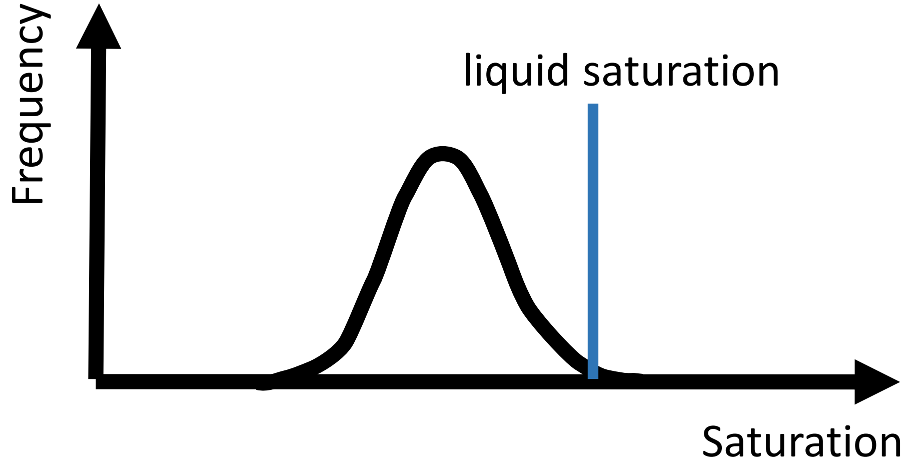
uses buoyancy information to diagnose mixing profiles based on extensive LES results

Bimodal cloud fraction scheme (Van Weverberg et al. 2021 MWR)

uses TKE and hydrometeor information from model to work out how much water will condense

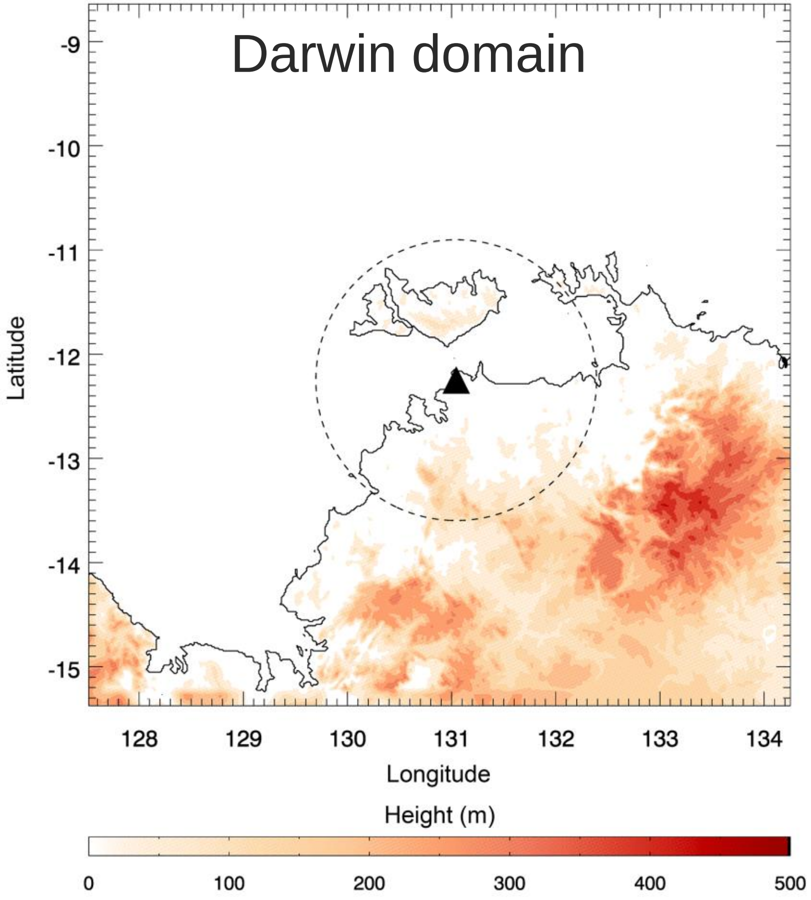






Dealing with mixed-phase in Bimodal cloud fraction scheme.

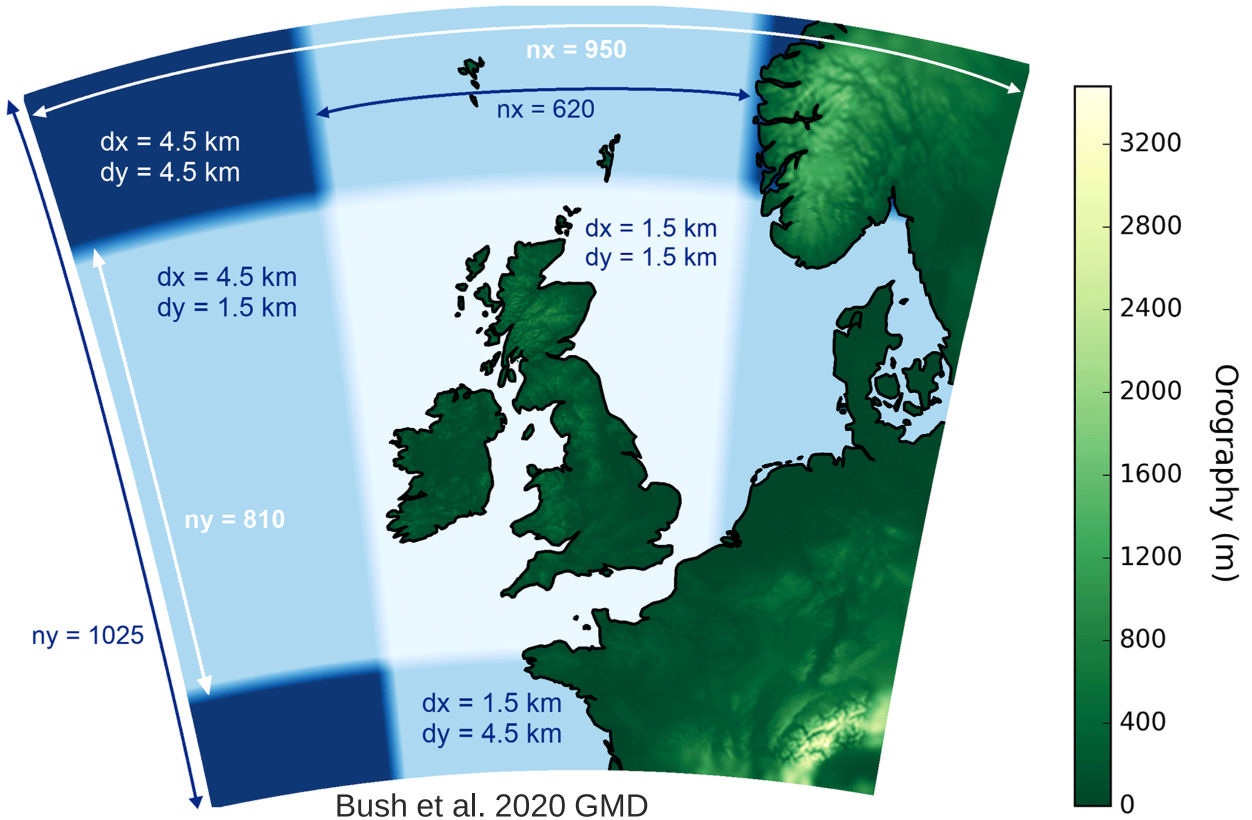
Tropical case study suite (Darwin). ~60 days from 1/21/2017- 3/17/2017 (0Z and 12Z simulation each day)
dx=1.5km, domain ~1300kmx1300km, 36h simulation



Bush et al. 2020 GMD

UKV case study suite. 120 cases spread over 2017-2019
dx=1.5km stretching to 4.5km at the outer rim, domain ~1300kmx1300km, 36h simulation

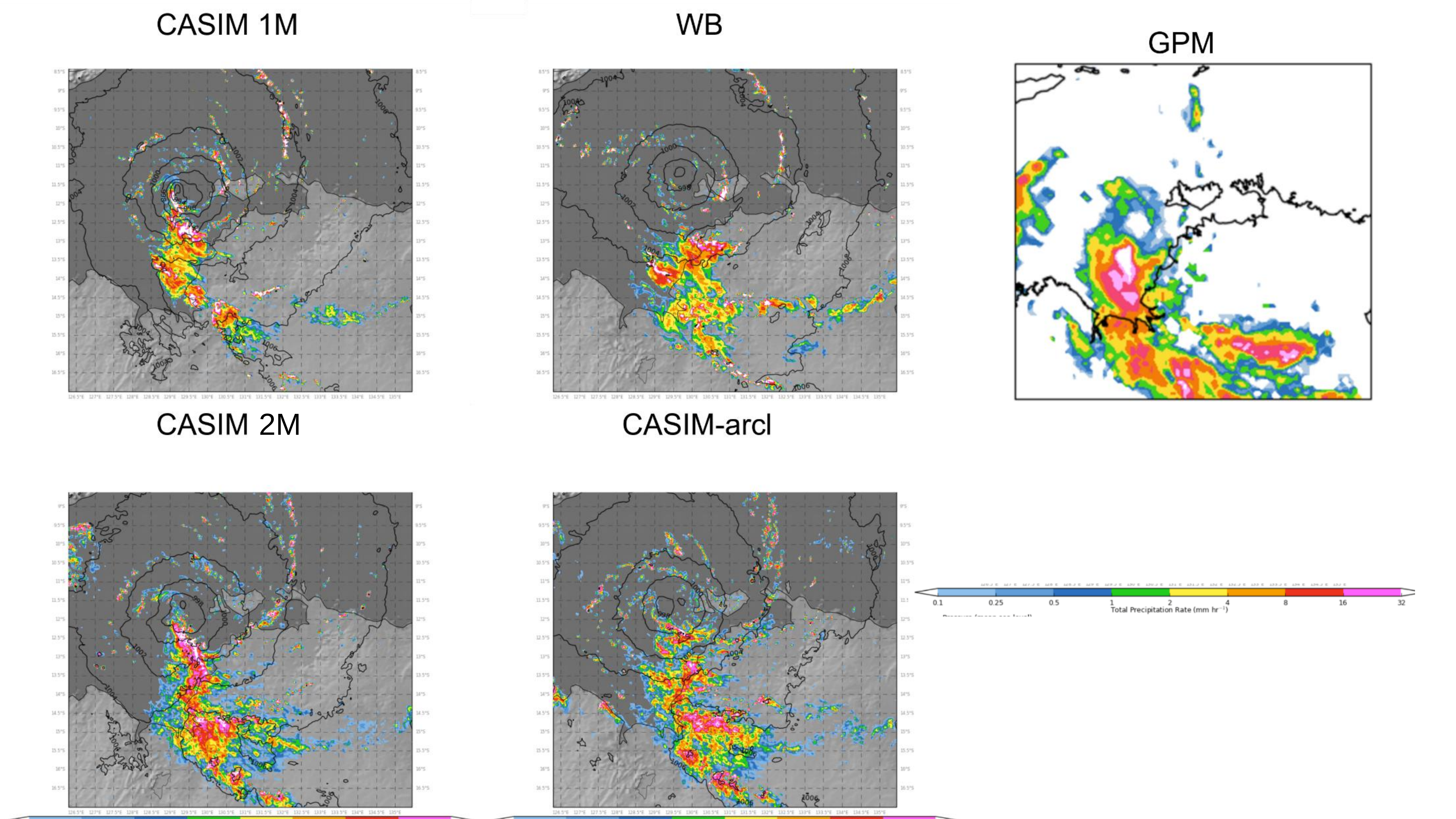
UKV domain

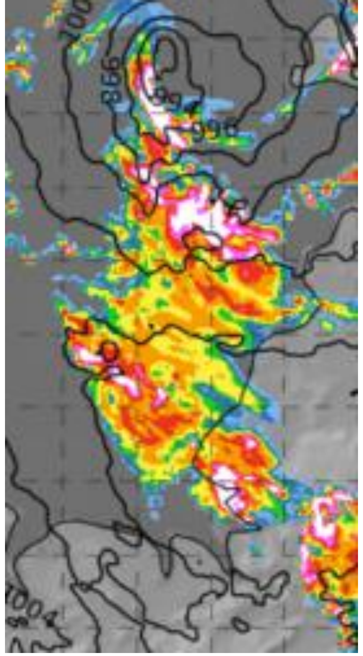


Bush et al. 2020 GMD

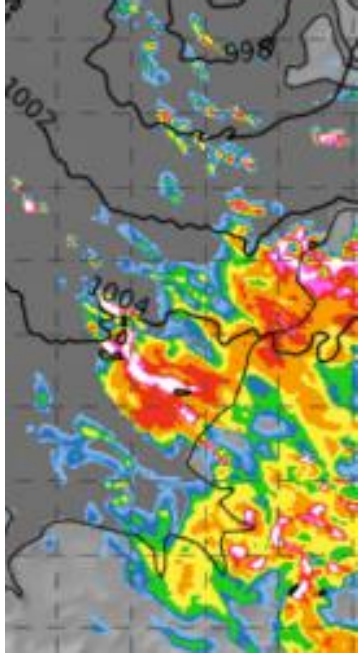
Configurations shown

	Scientifically similar single moment		Double moment	
			Set incloud cdnc	Simple aerosol
Cloudscheme\microphysics	**Wilson and Ballard**	**CASIM-1M**	**CASIM-2M**	**CASIM-arcl/murk**
SMITH	RAL2-M			
PC2	RAL2-T			
BIMODAL	WB	*	RAL3	*


CASIM 1M
WB
GPM
CASIM 2M
CASIM-arcl
0.1
0.25
0.5
1
2
4
8
16
32
Total Precipitation Rate (mm hr⁻¹)

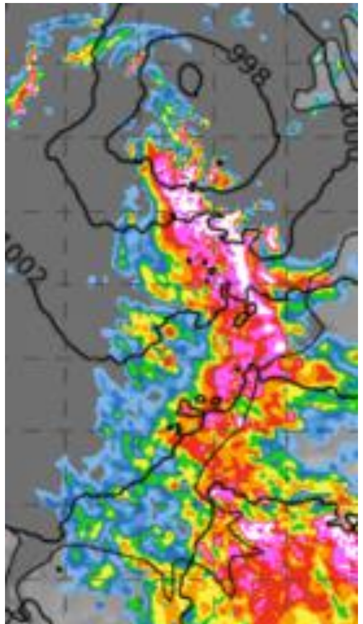


casim-1M

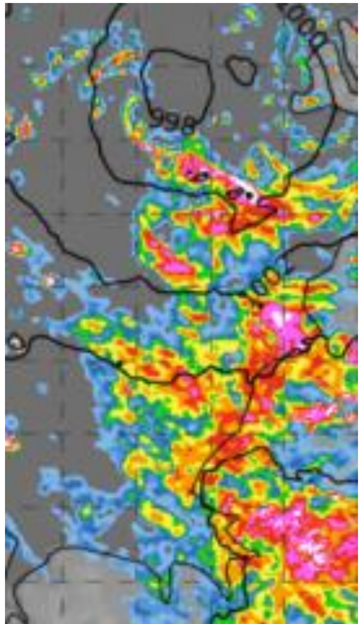


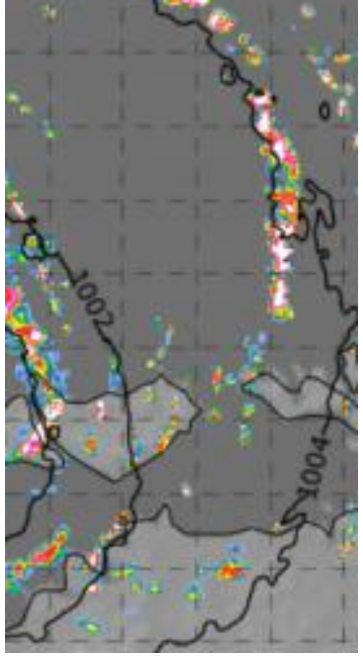
WB

casim 2M

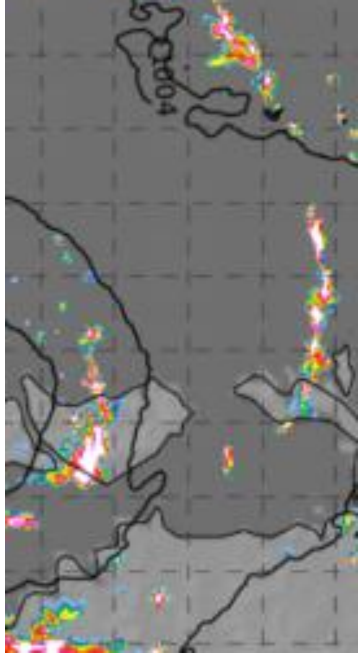


casim-arcl



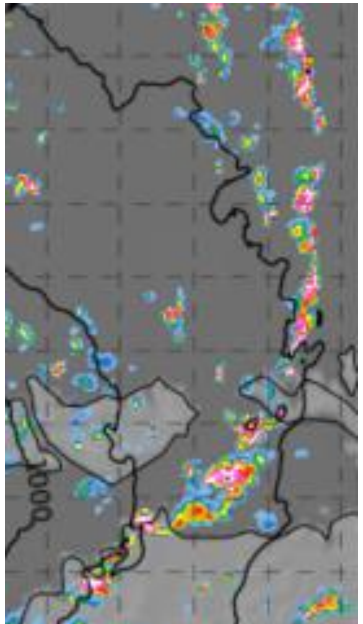


casim-1M

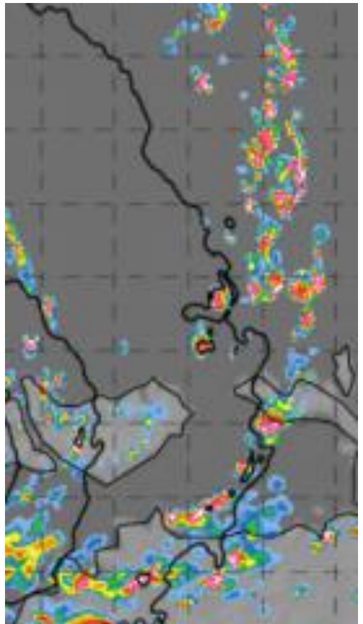


WB

casim 2M

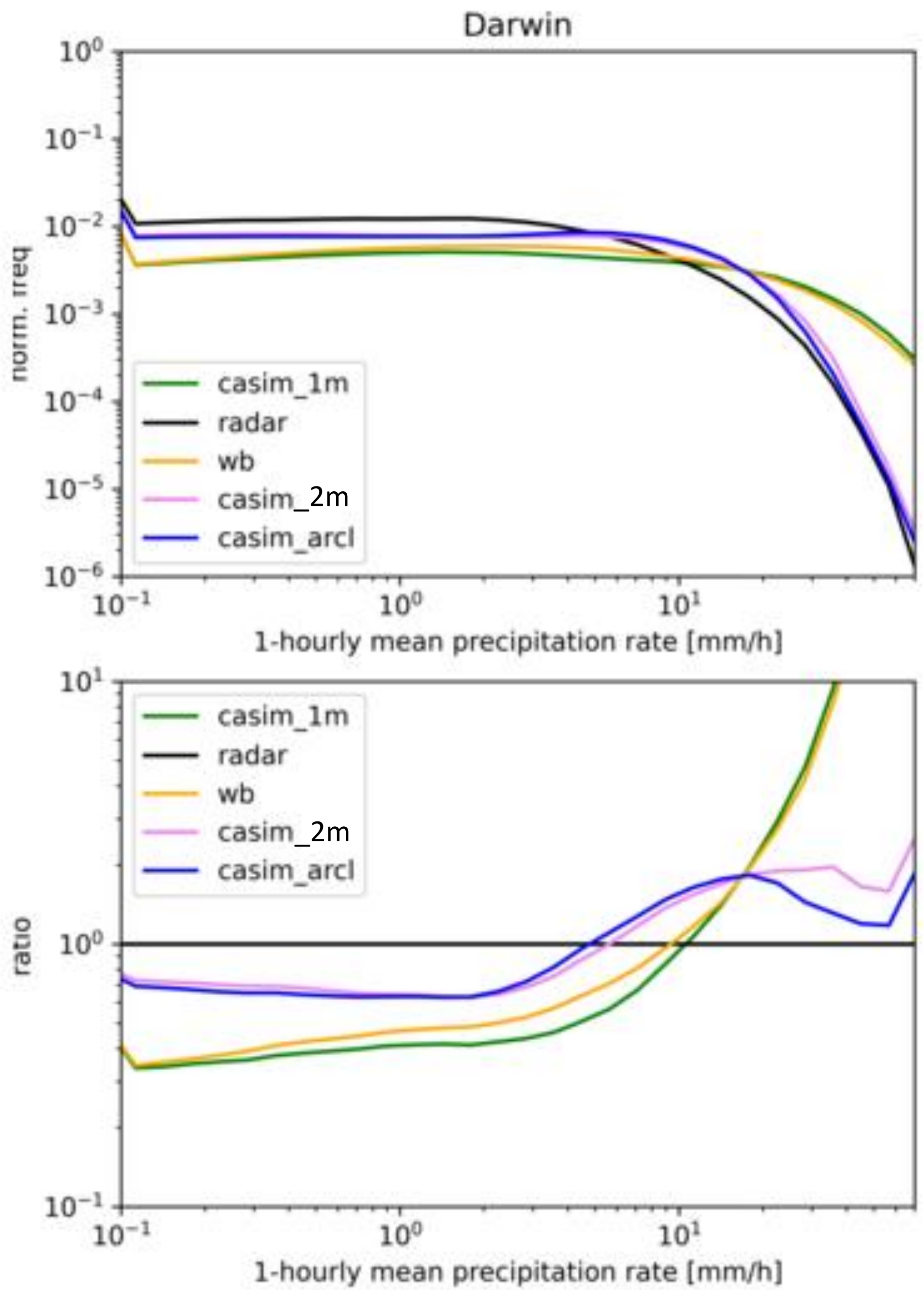


casim-arcl



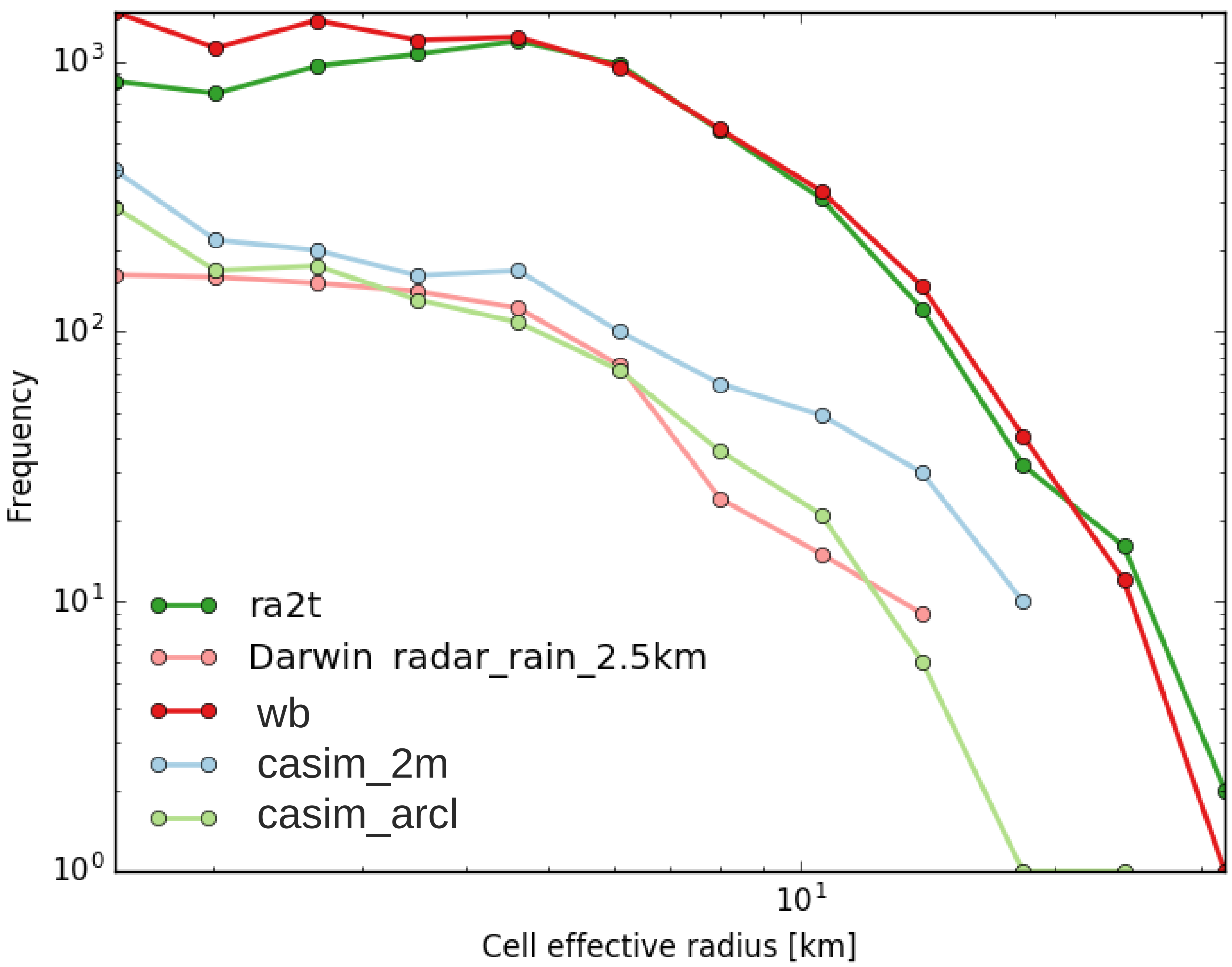
Single moment

Double moment



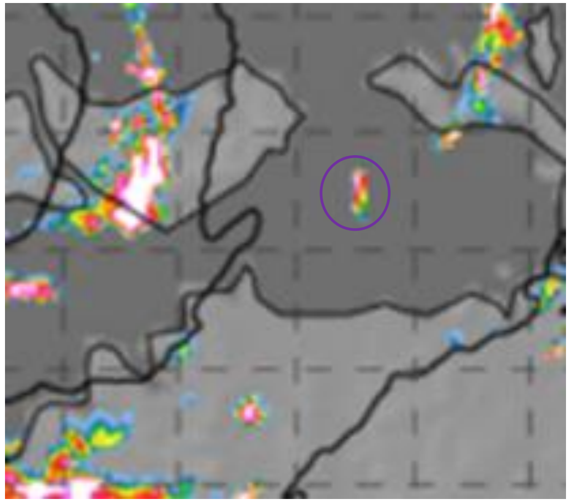
Precip rate distributions from 120 cases

Precip rate distributions normalised by radar obs from 120 cases



Cell precip threshold>32mm/h

CASIM exhibits smaller cell sizes compared to WB – less ‘blobby’

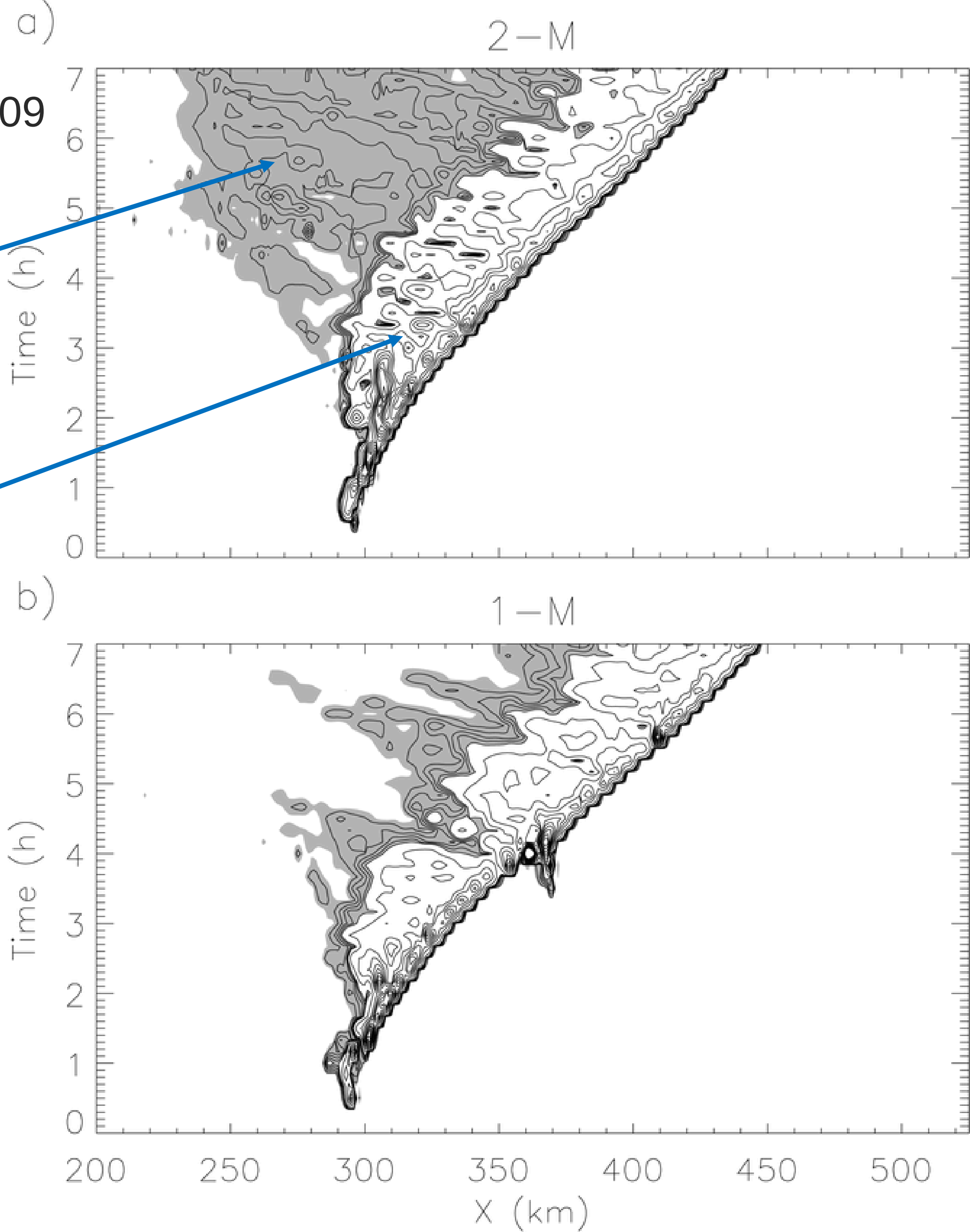


2-M vs 1-M

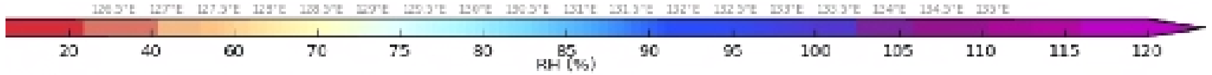
Morrison et al. 2009 MWR

Reduced rain evap for 2M compared to 1M in **strat** region

Increased rain evap for 2M compared to 1M in **conv** region



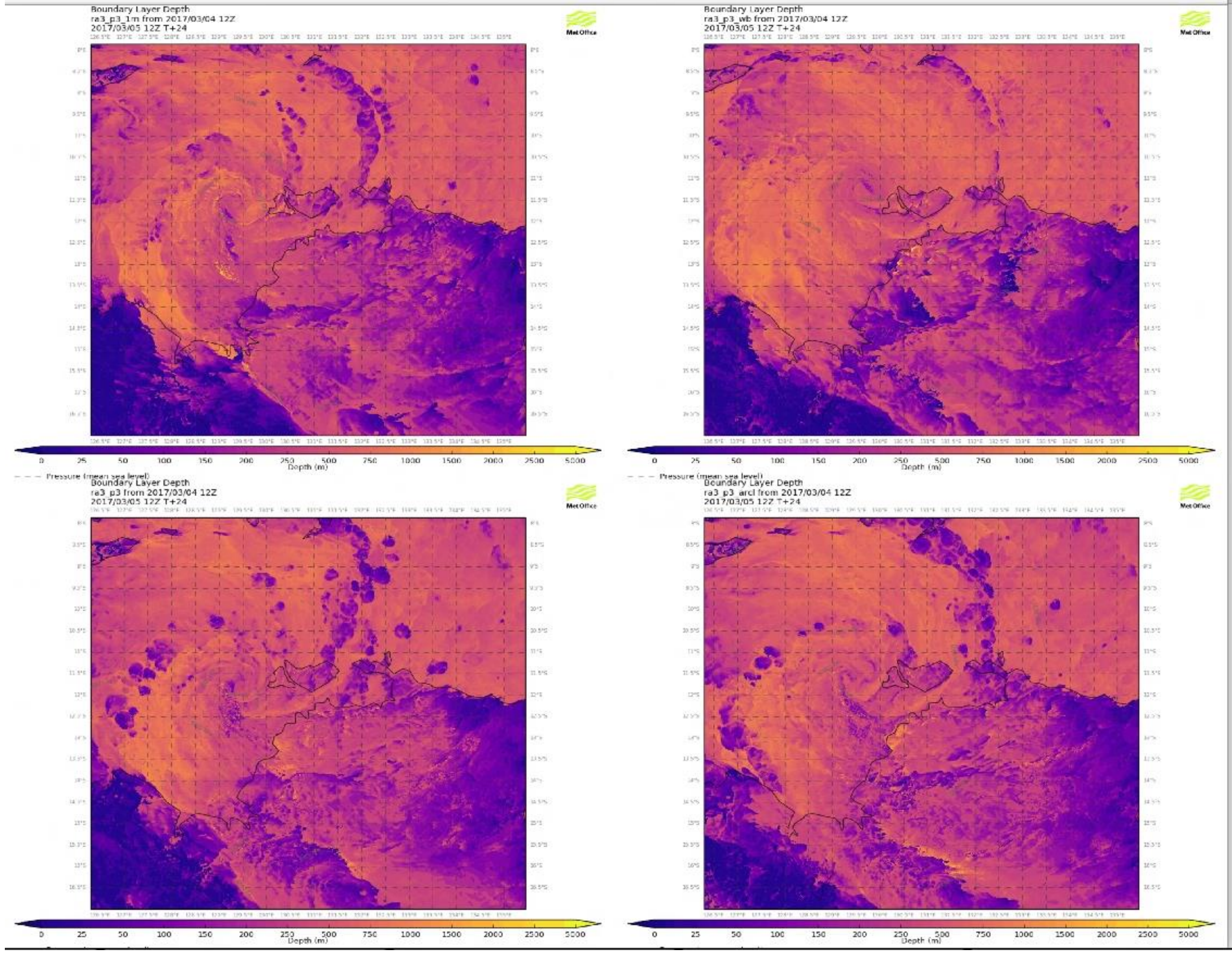
Boundary Layer Depth

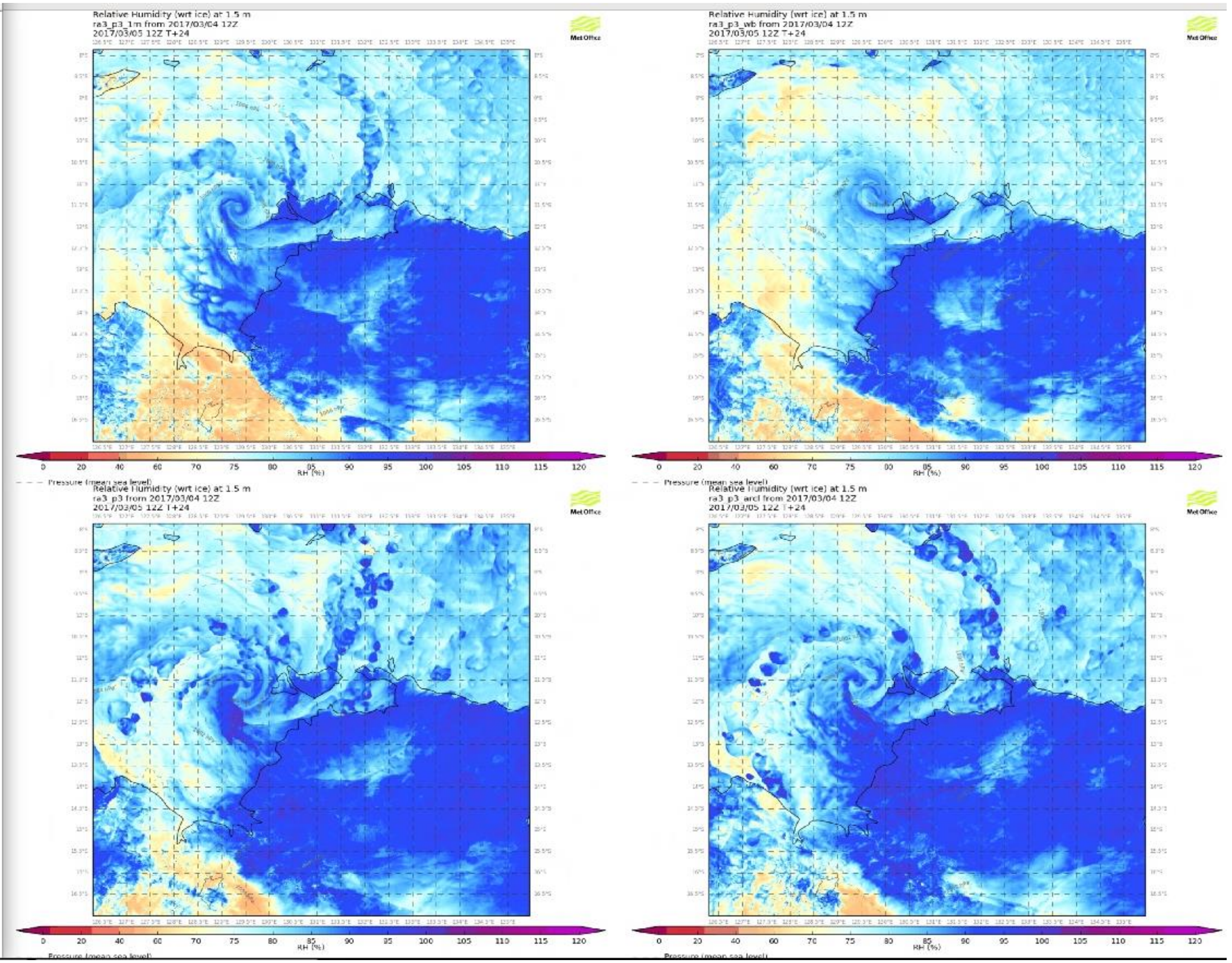


RH 1.5m

Casim_1m wb

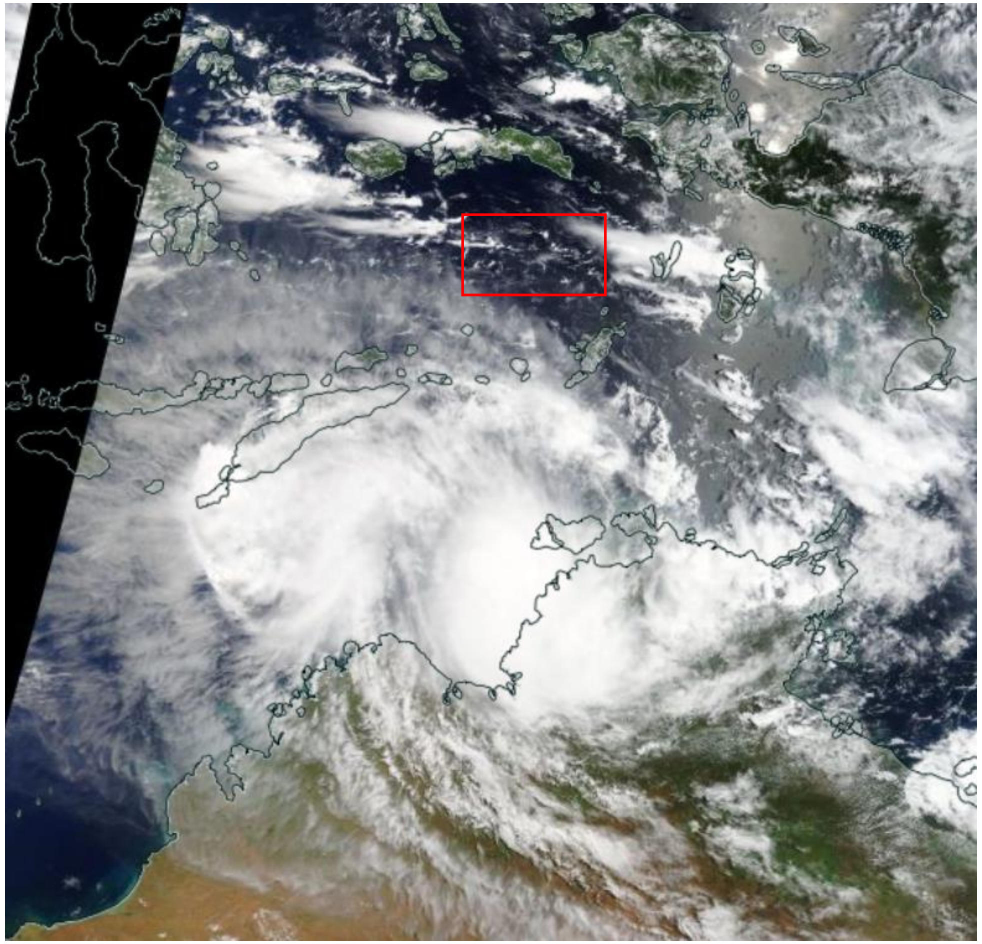
Casim_1m wb

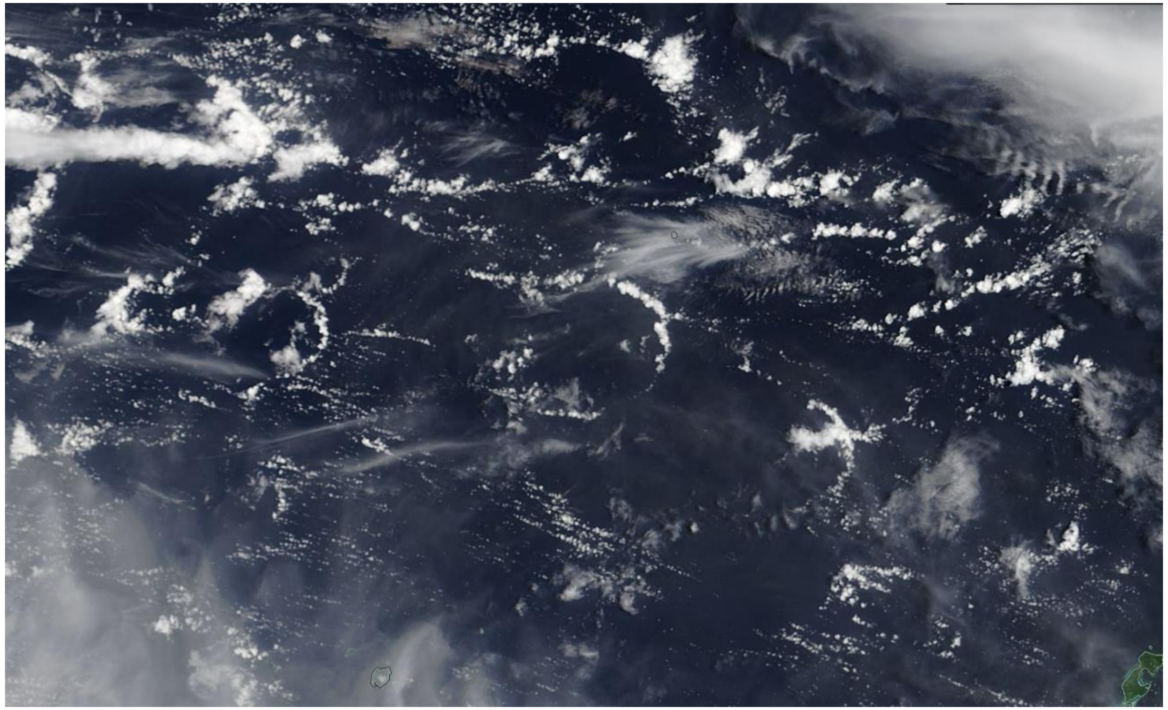




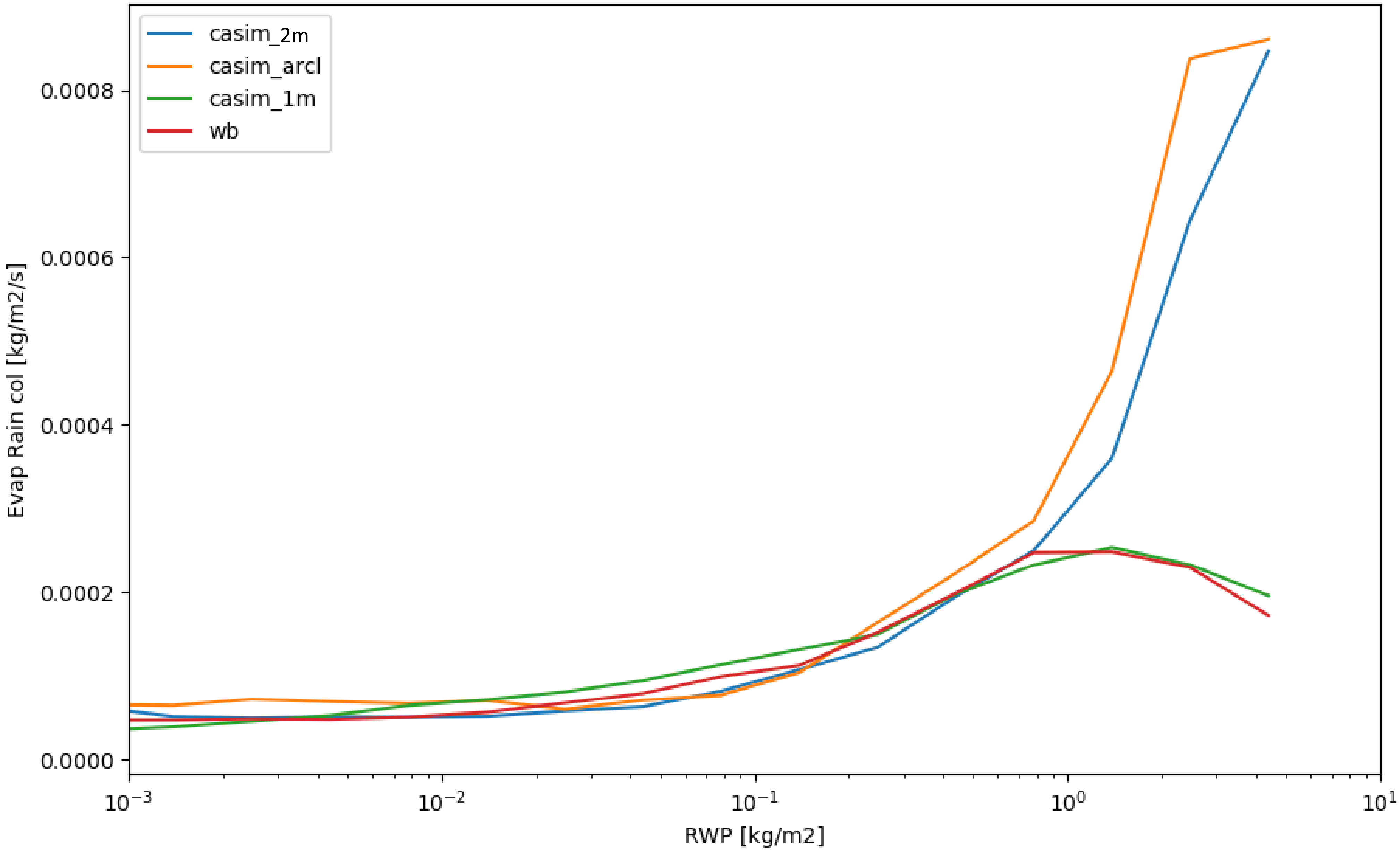
Casim_2m Casim_arcl

Casim_2m Casim_arcl

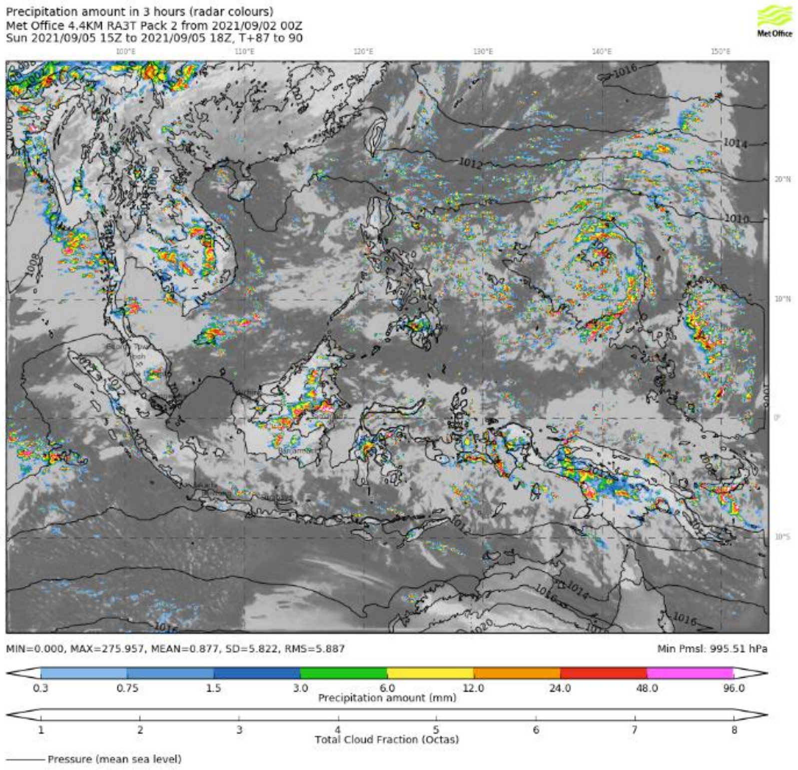




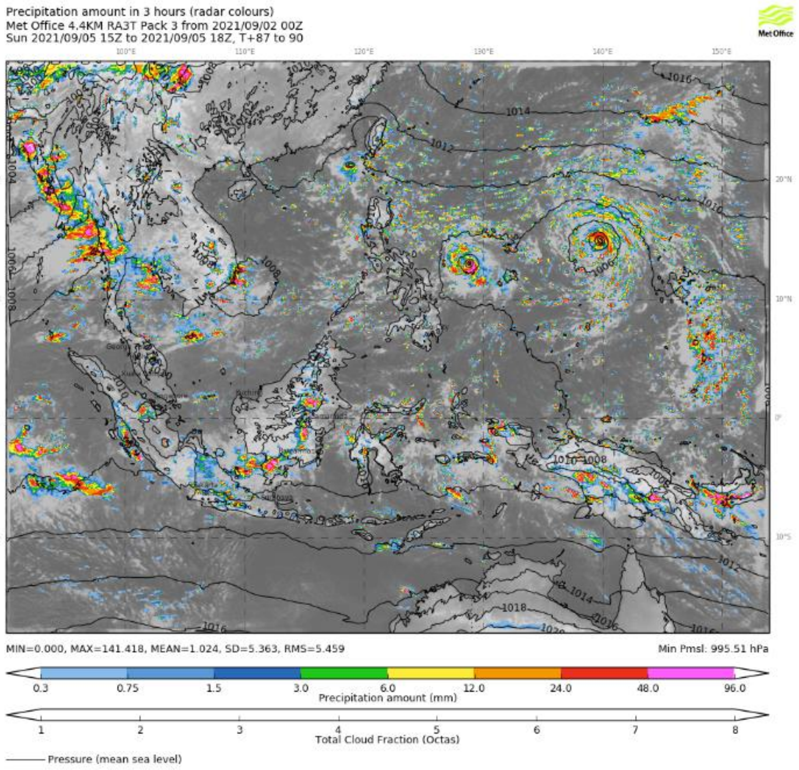
Column integrated rain evap



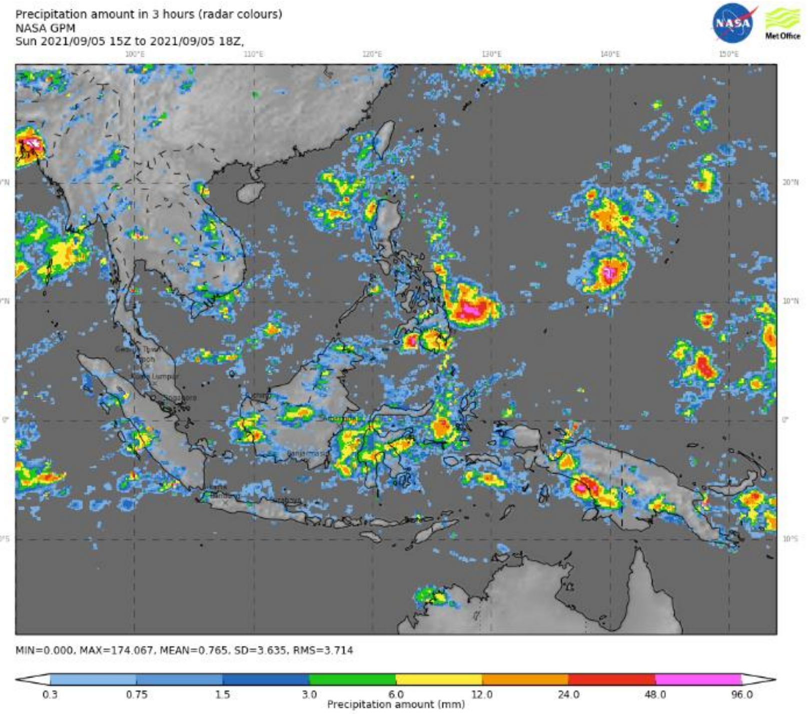
South East Asia 4.4km realtime monitoring (S. Webster)



RA3T pack2
Old microphys+PC2

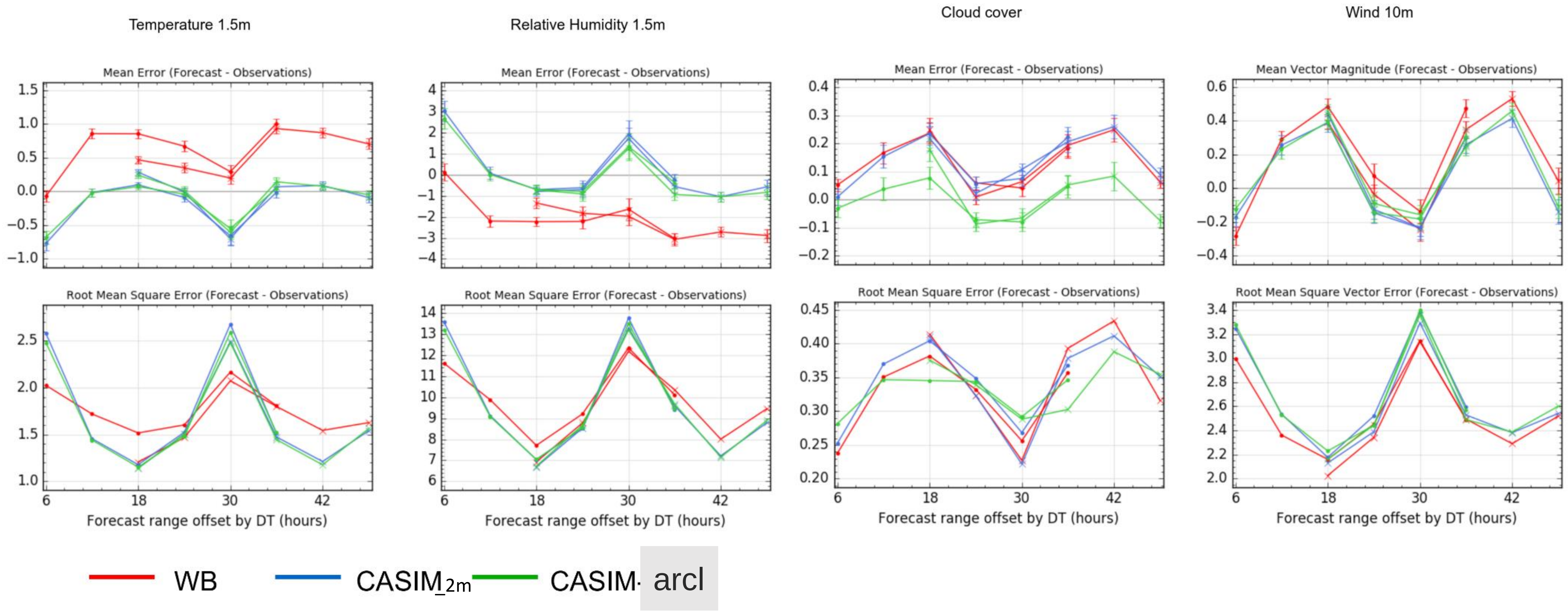


CASIM
RA3 pack3



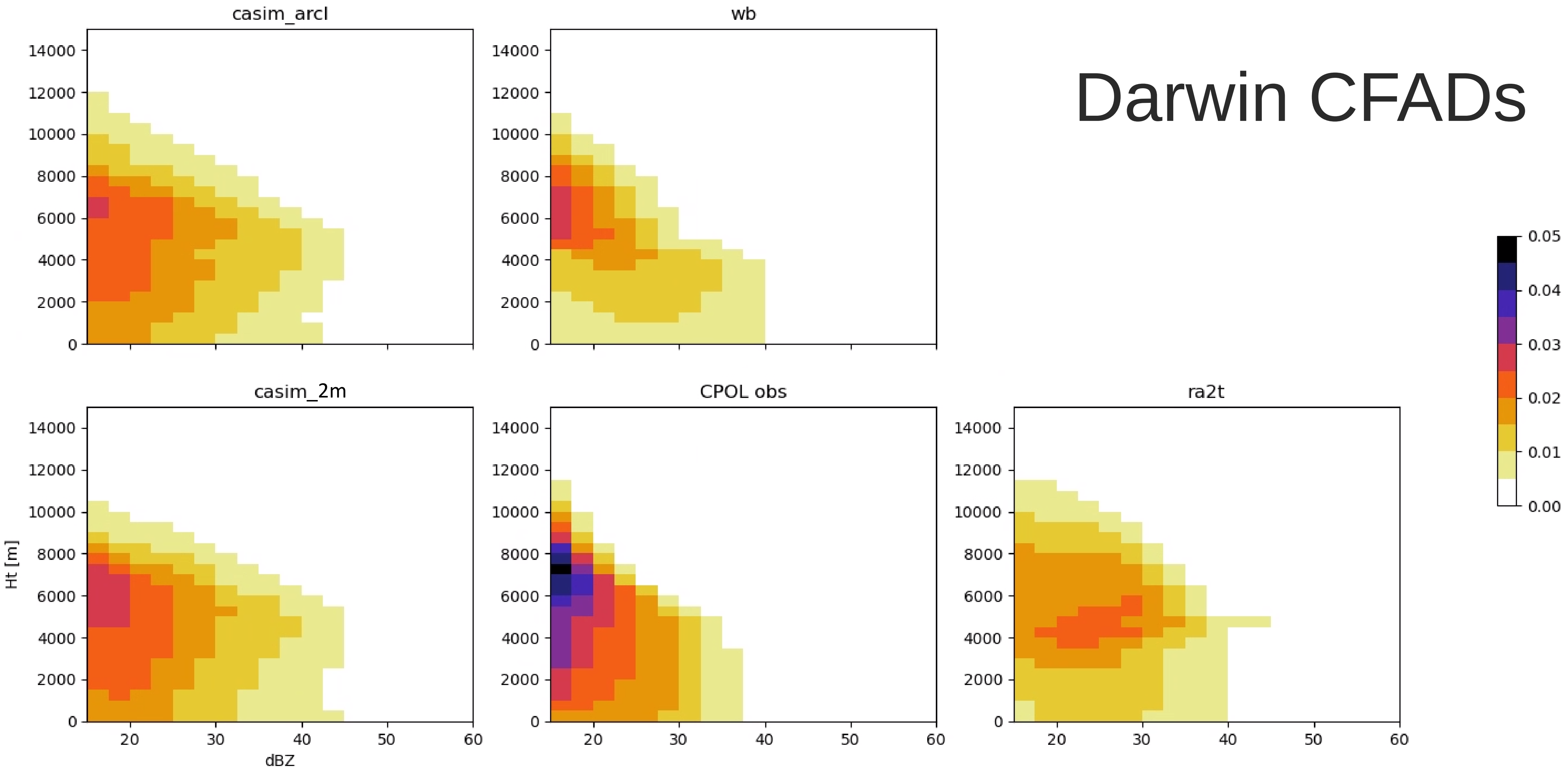
GPM

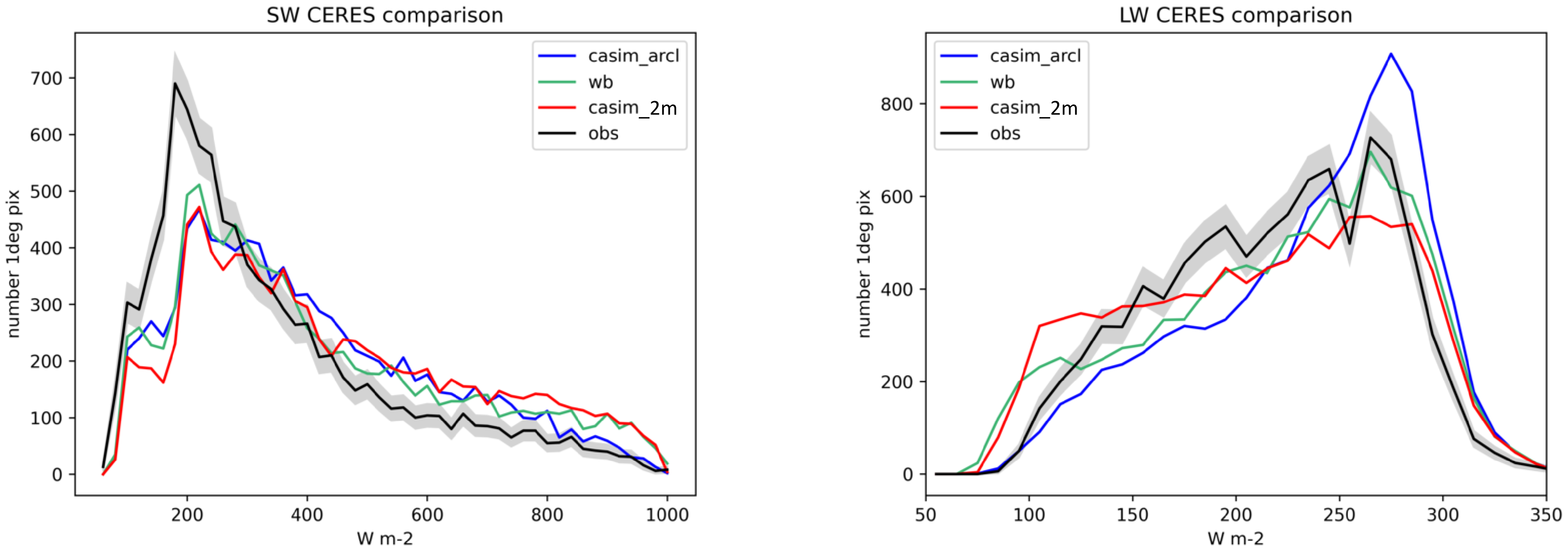
T+90 forecast accurately captures formation of 2 TCs for RA3 pack3 that are missing for pack2



Comparison to synoptic obs at Darwin for 120 cases. 60 starting at 00Z, 60 starting at 12Z.

Darwin CFADs





SW CERES comparison
casim_arcl
wb
casim_2m
obs
number 1deg pix
W m-2
0
100
200
300
400
500
600
700
200
400
600
800
1000
LW CERES comparison
casim_arcl
wb
casim_2m
obs
number 1deg pix
W m-2
0
200
400
600
800
50
100
150
200
250
300
350

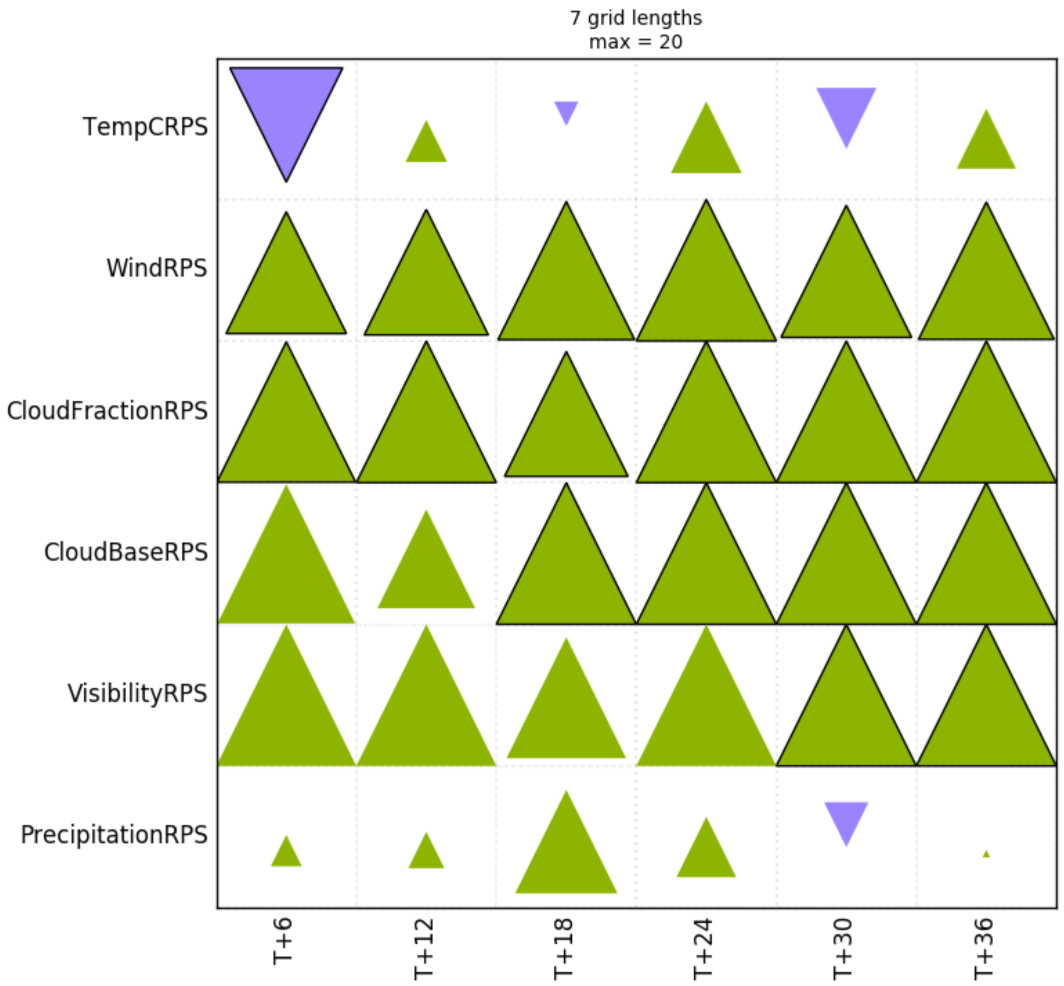
Model performance summary scorecards as a function of forecast lead time

CASIM vs RAL2
Darwin

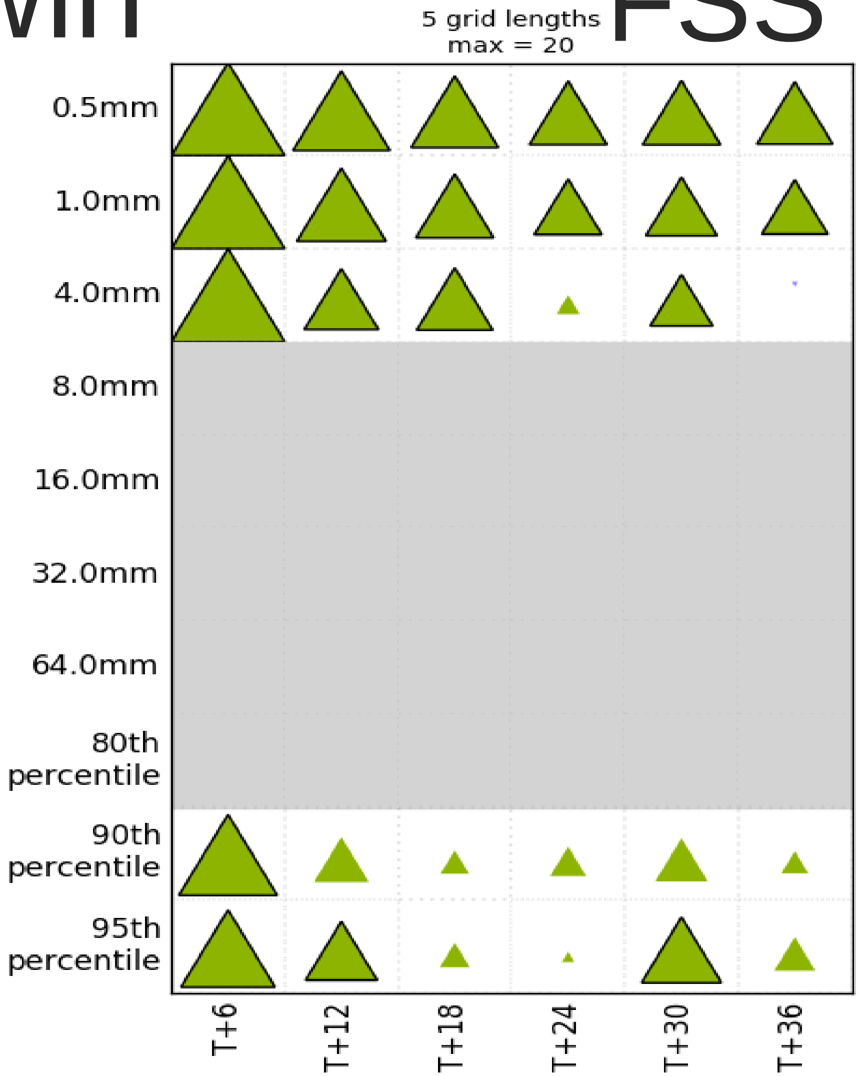
HiRA

Darwin

FSS



Δ ranked probability skill scores for near surface synoptic observations



Δ fractional skill score for precipitation on the right.

Green triangles = improvement by the CASIM configuration relative to the operational model.

Blue triangle = degradation.

Bold outlines = difference is statistically significant.

10 OFEG tickets deemed as major or high deficiencies for the UKV.

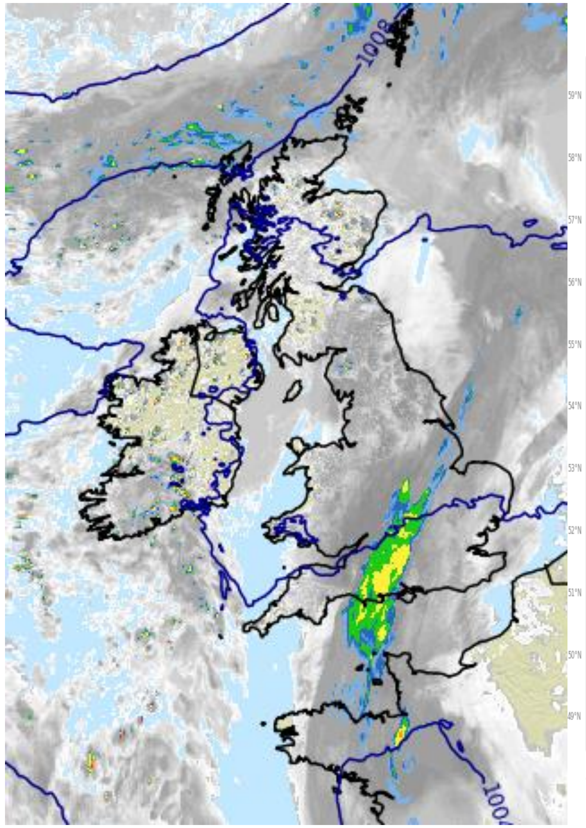
Tickets have been open for 3-8 years.

Examples from tickets:

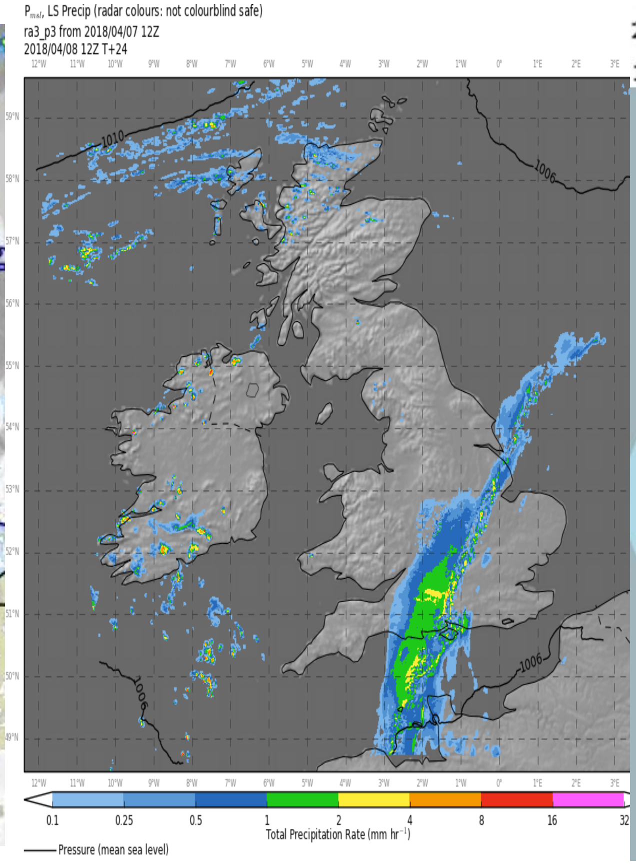
Ticket	Summary	
#532	Minimum temperatures too high and maxima too low (UKV)	major
#525	Lack of Light Rain and Drizzle - RMED#72	high
#526	Unrealistic Fragmentation of Precipitation Bands - RMED#56	high
#529	Excessive development of showers in intensity and distribution - RMED#73	high

Unrealistic Fragmentation of Precipitation Bands #526
lack of light rain – too much heavy rain #525

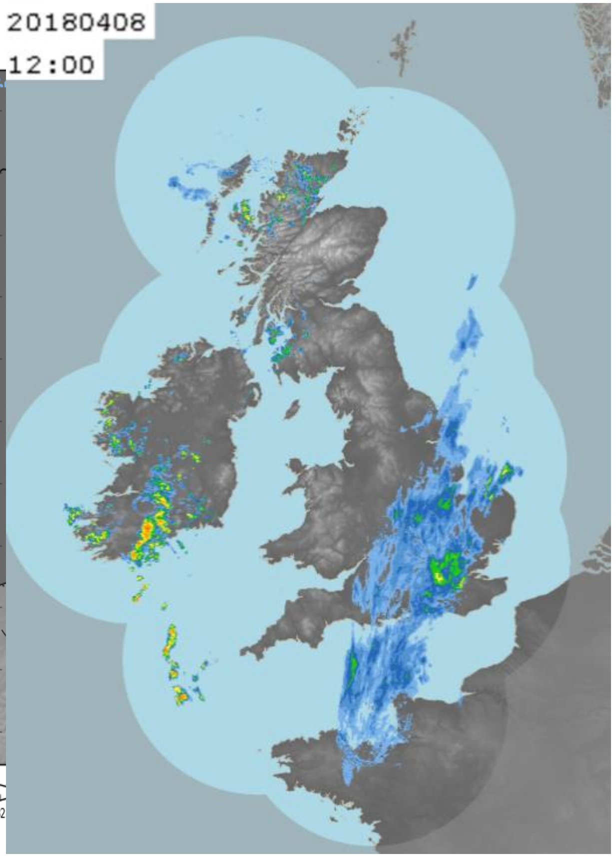
RAL2M



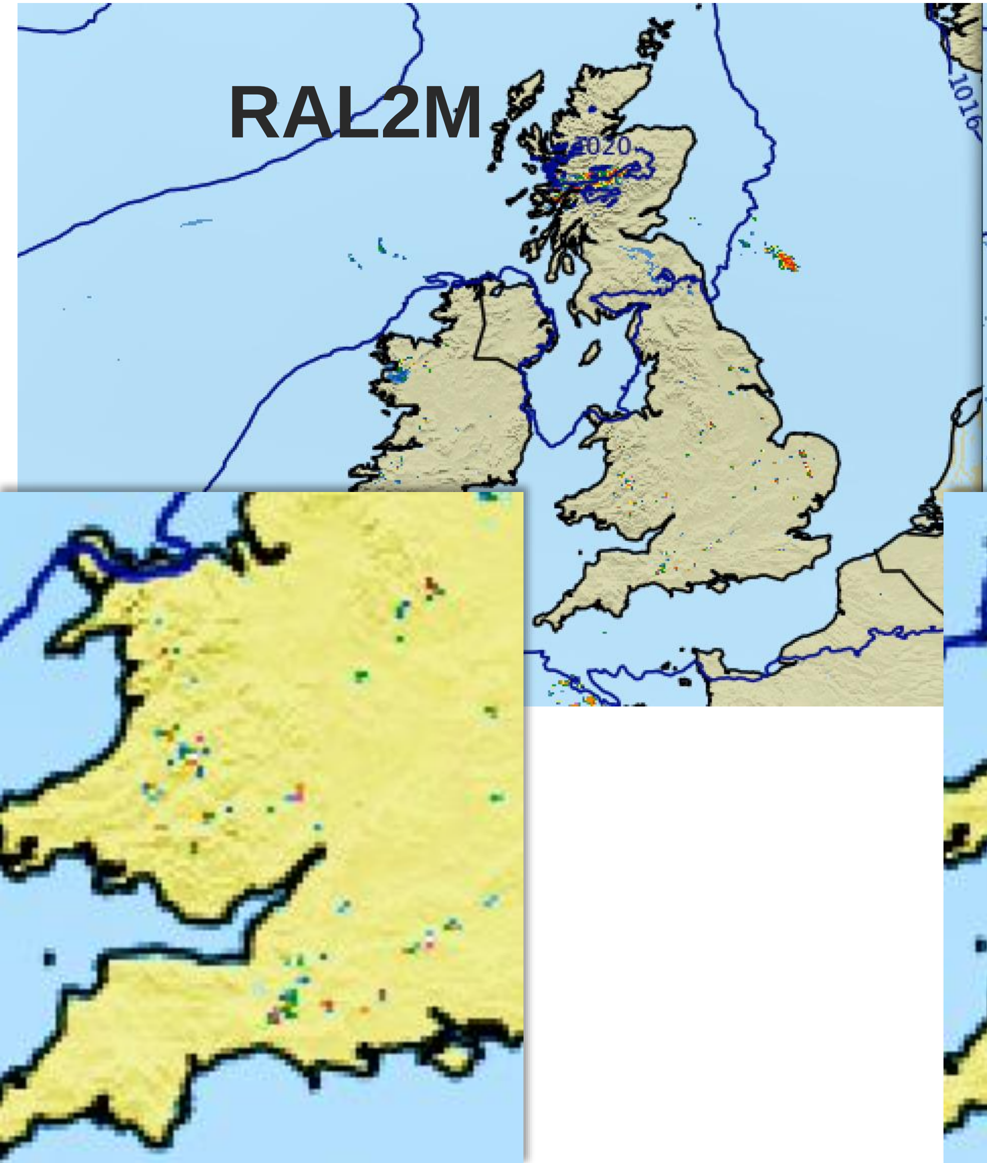
CASIM

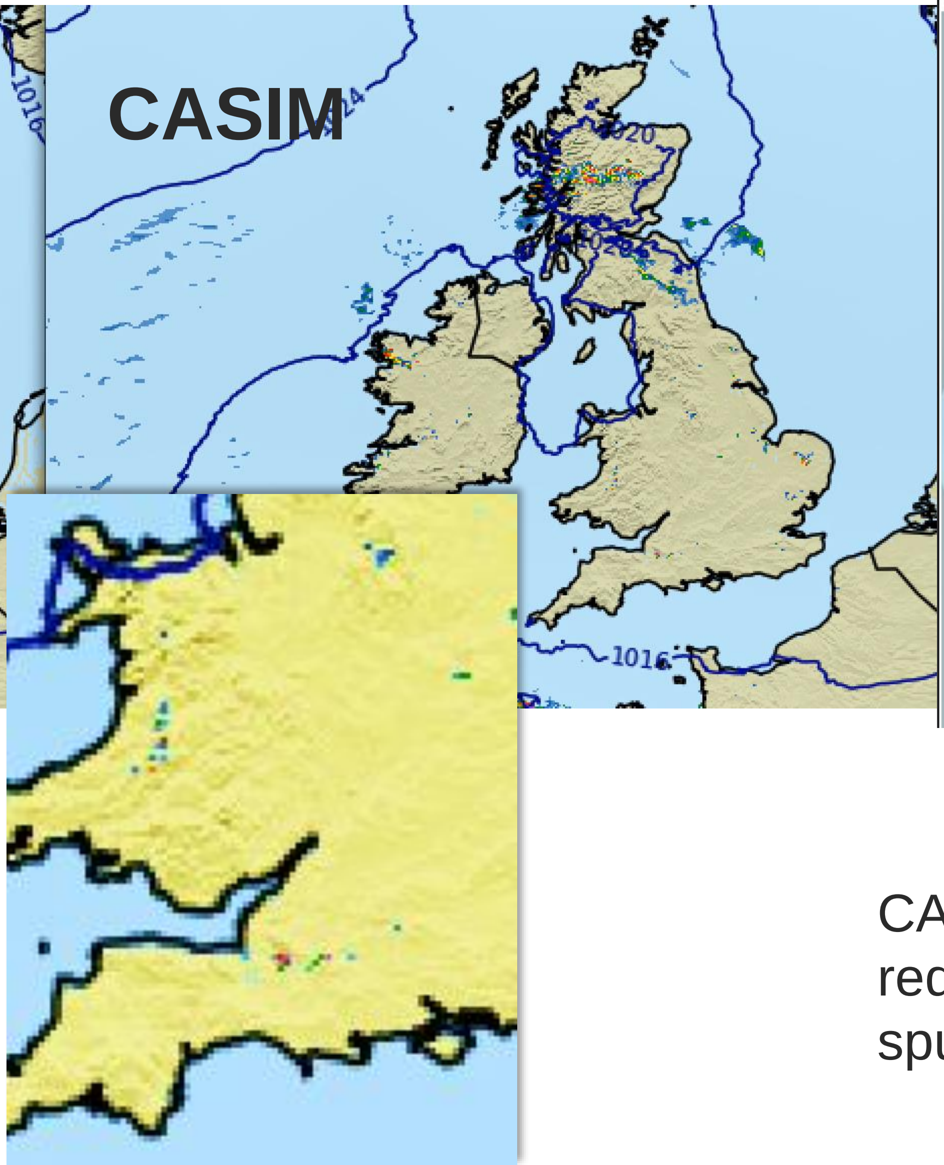


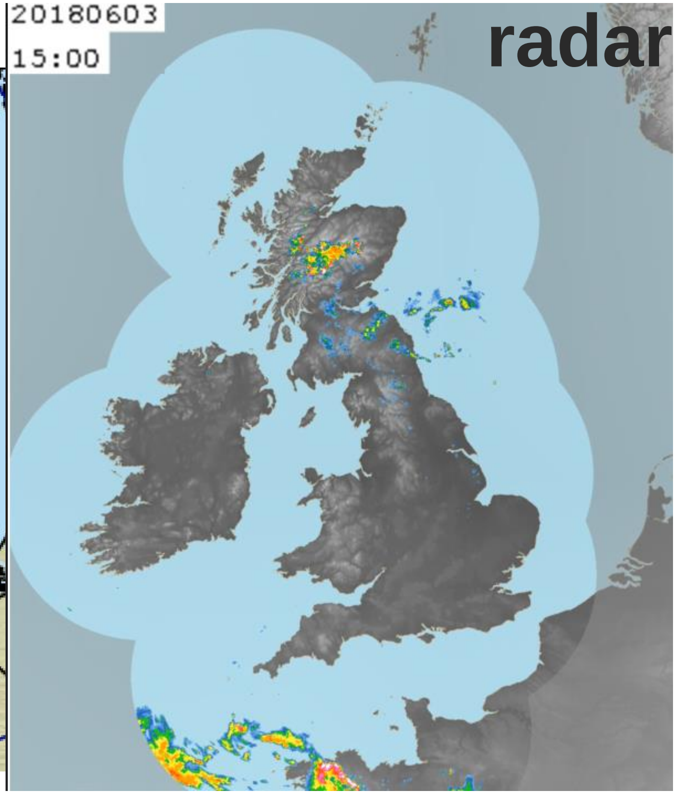
RADAR precip.



Excessive development of showers in intensity and distribution #529





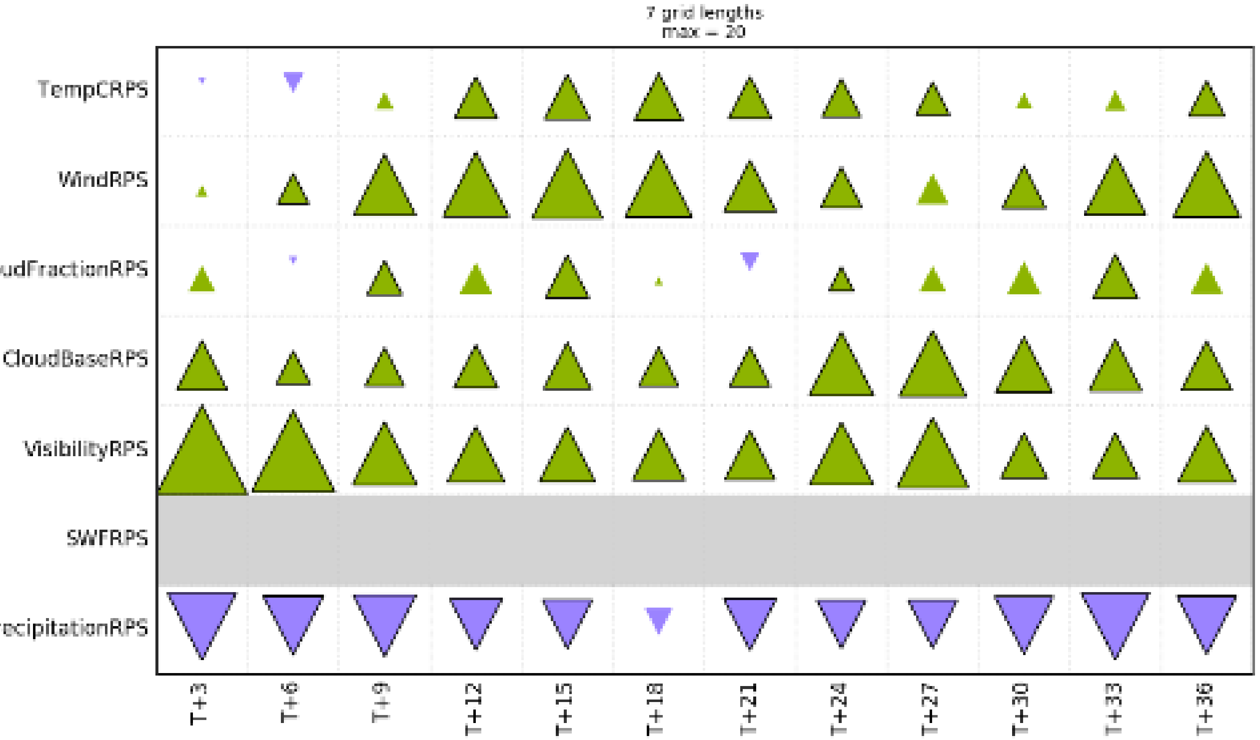


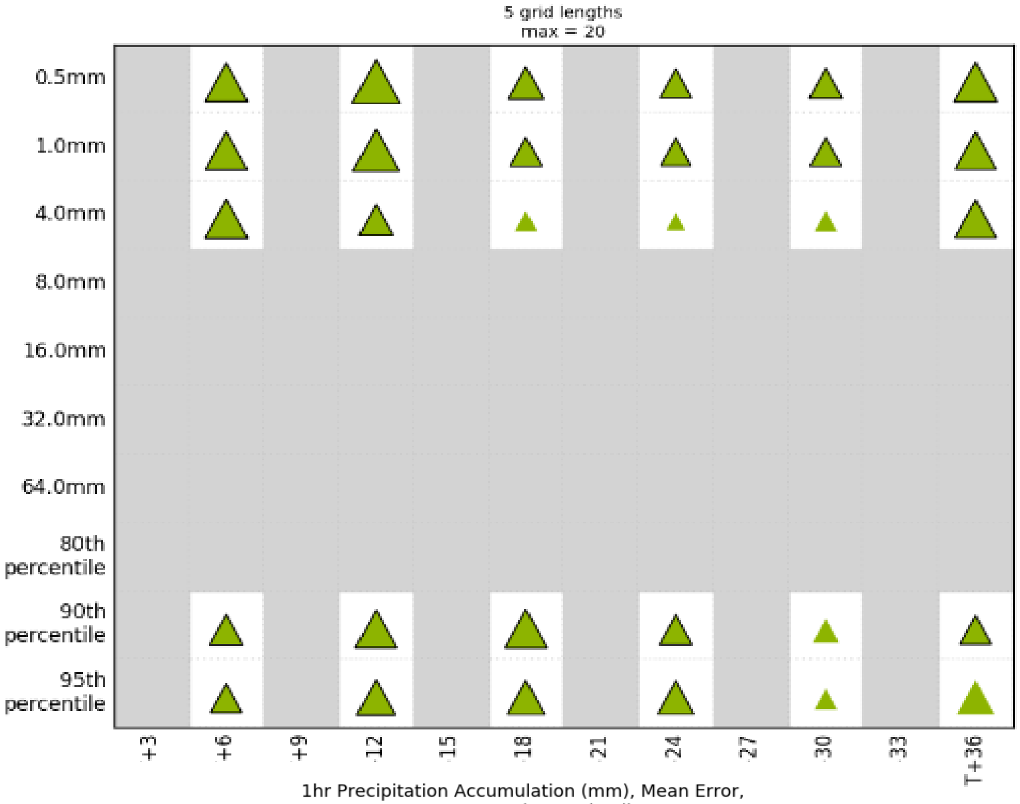
CASIM in RAL3 has reduced frequency of spurious showers

HiRA

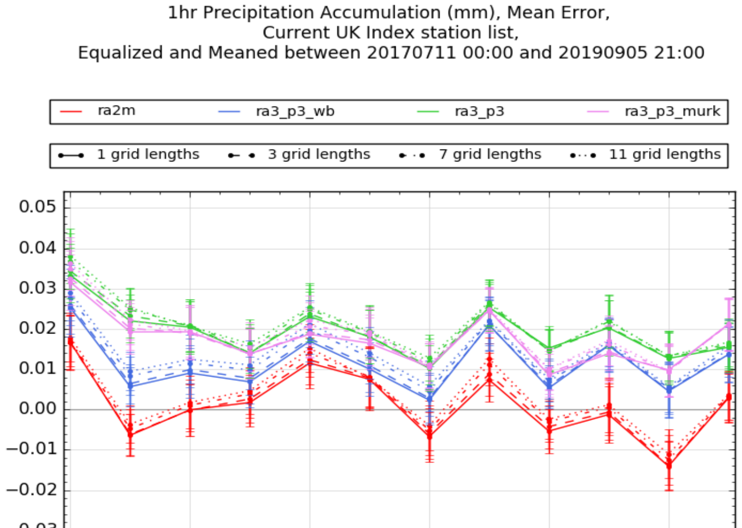
UKV

FSS



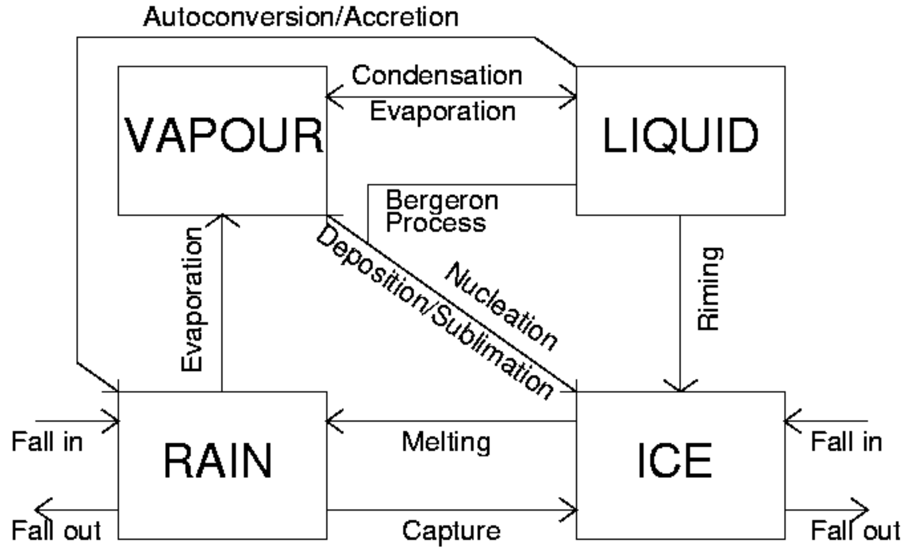


Unclear why HiRA precip is worse when FSS is improved and qualitative performance in terms of structure and rainrate histogram is also better. One potential reason is a +0.02mm/h precip bias that could be tuned out in future configurations



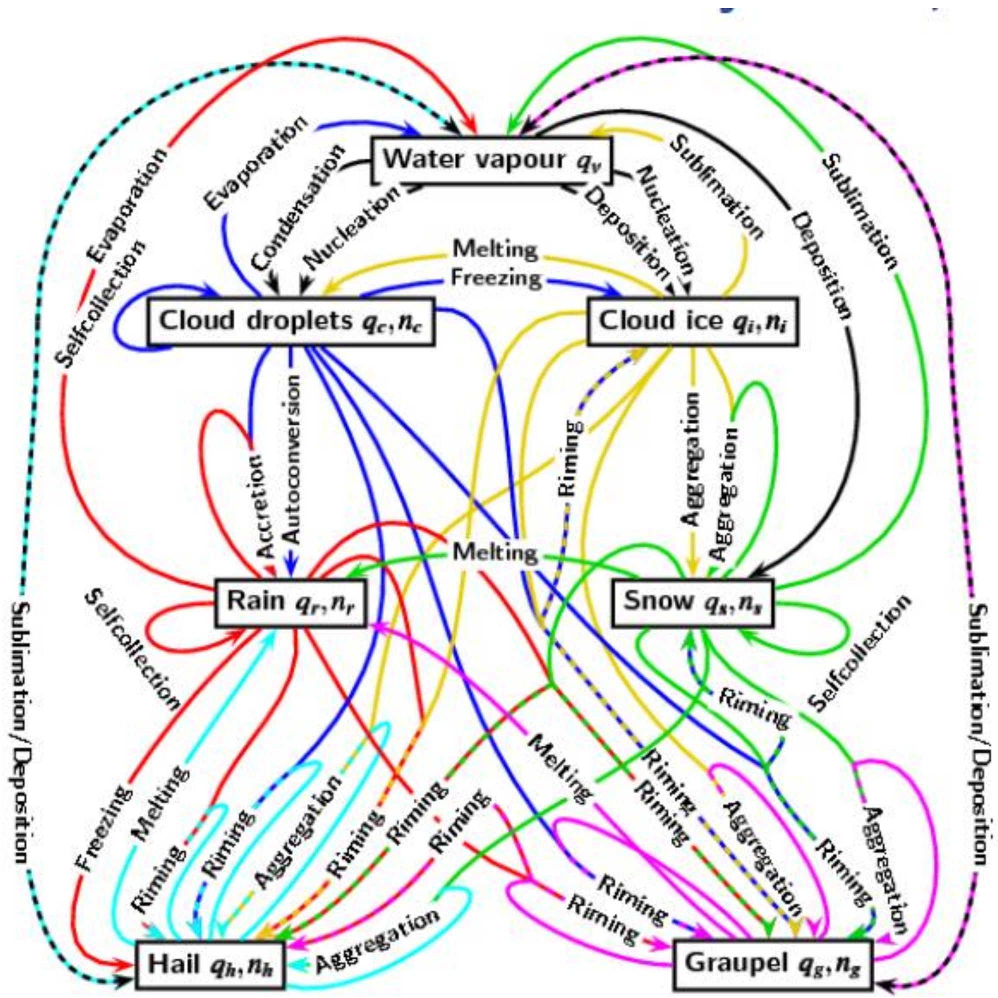
Unknowns

- More degrees of freedom requires mor



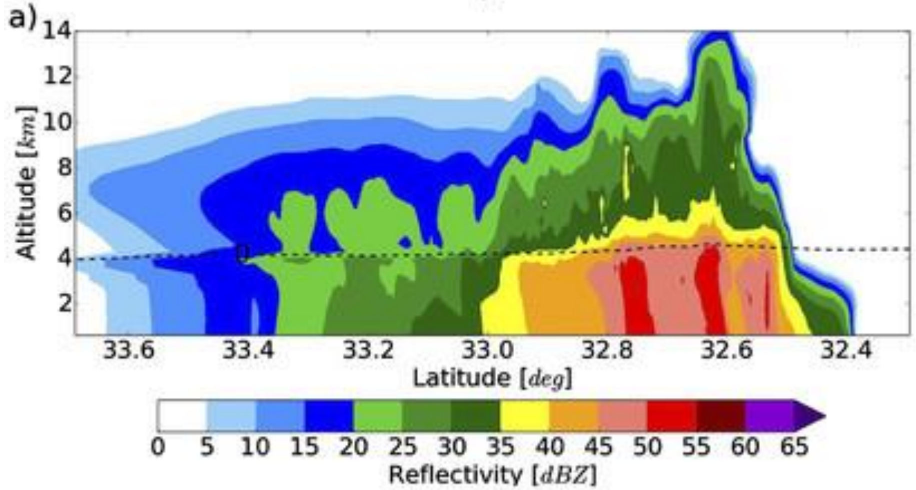
Wilson and Ballard

1M-2M

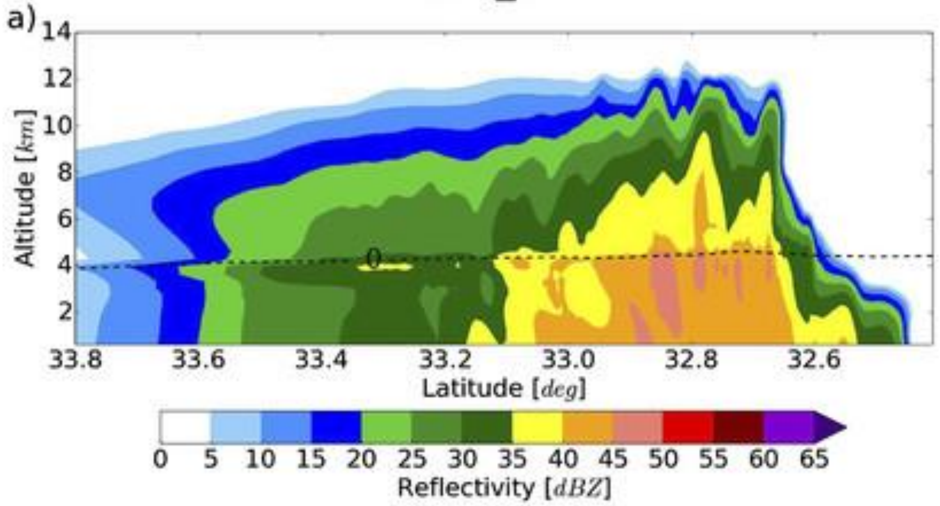


Seifert and Beheng

CLN_3A



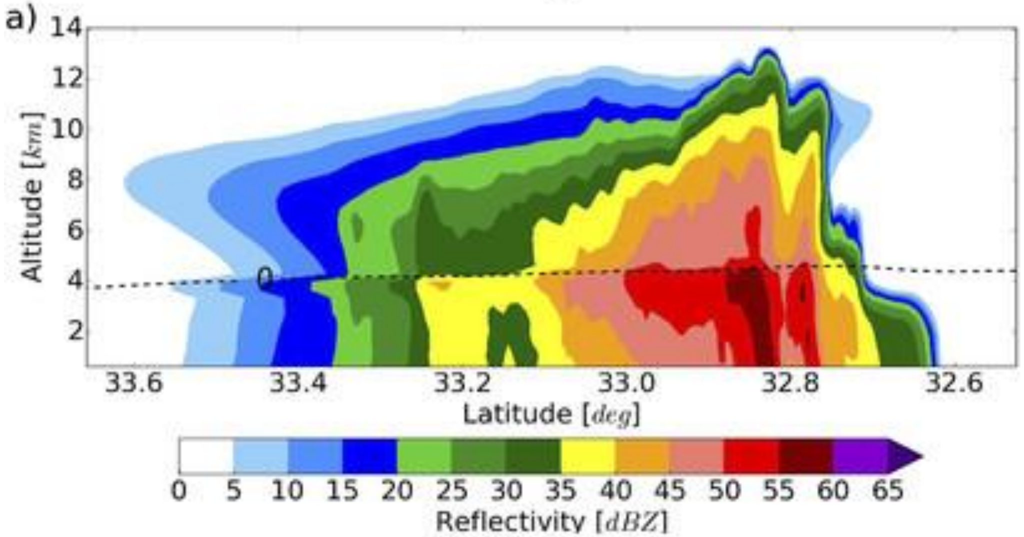
CLN_3B



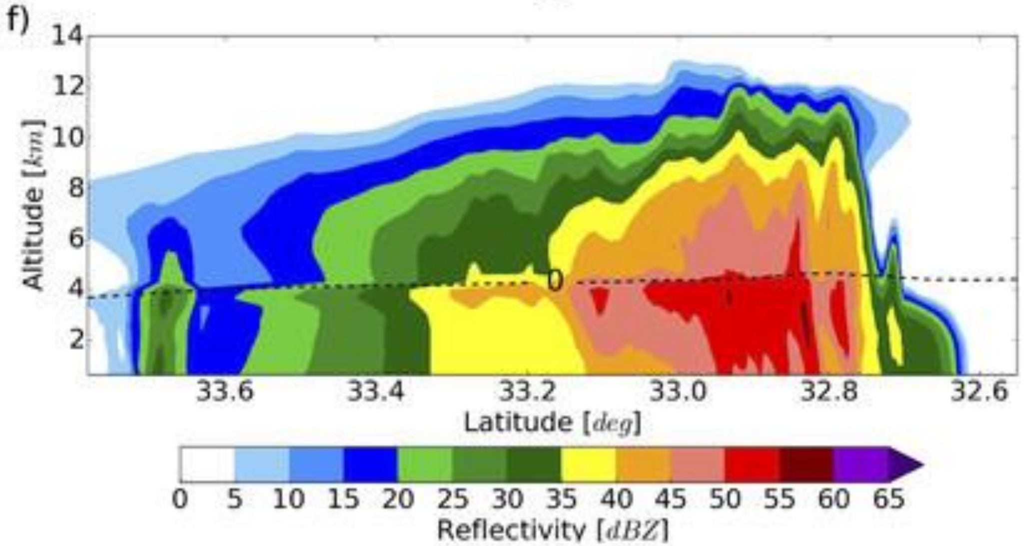
Jouan and Milbrandt 2019

Sensitivity to changing graupel density (3A,B) or graupel-drop collision efficiency (2A,B)

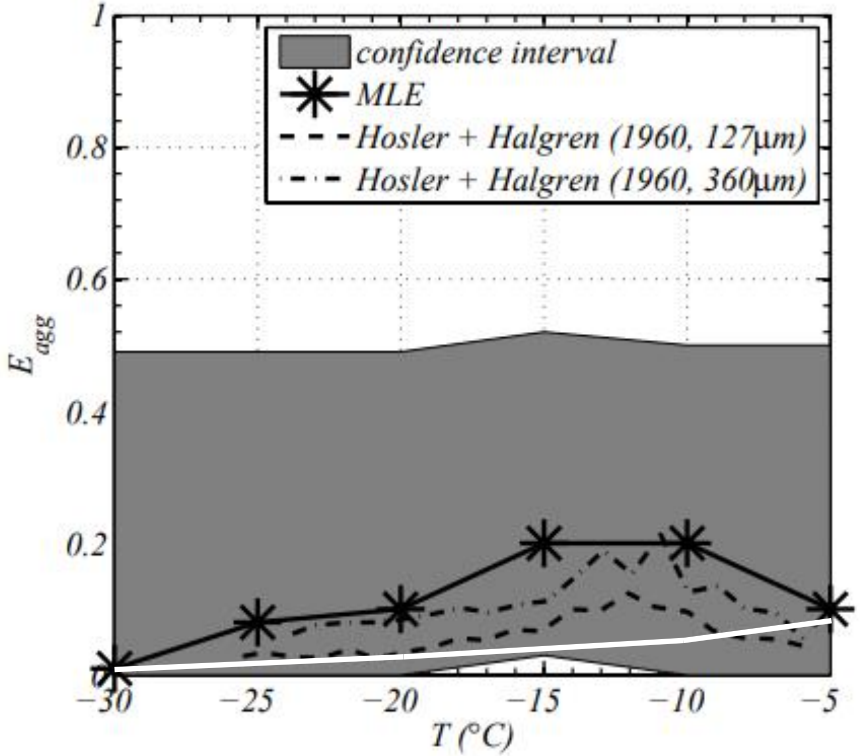
CLN_2A

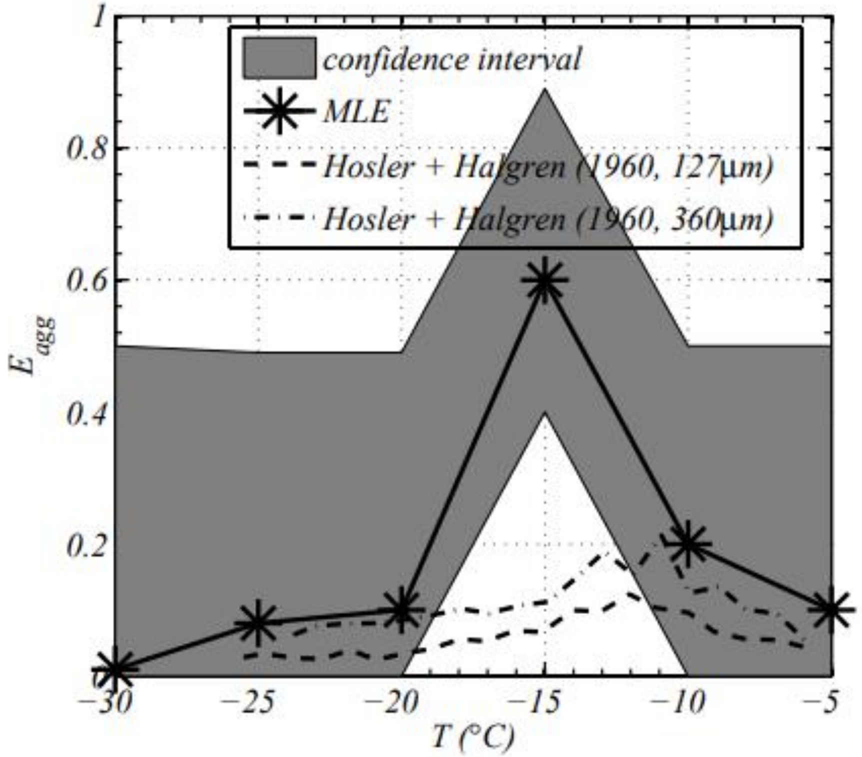


CLN_2B



Snow aggregation

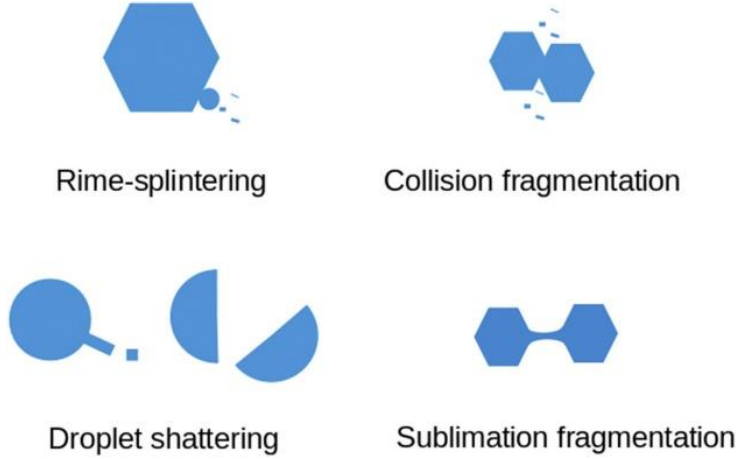




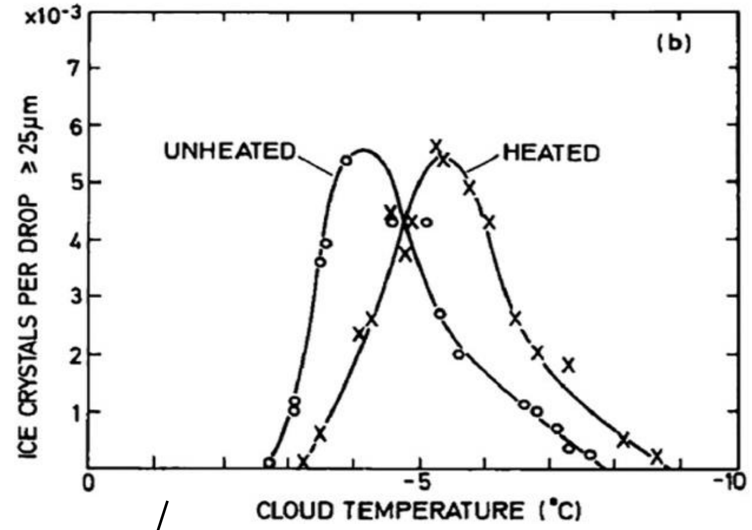
Connolly et al. 2015 ACP

Big Unknowns

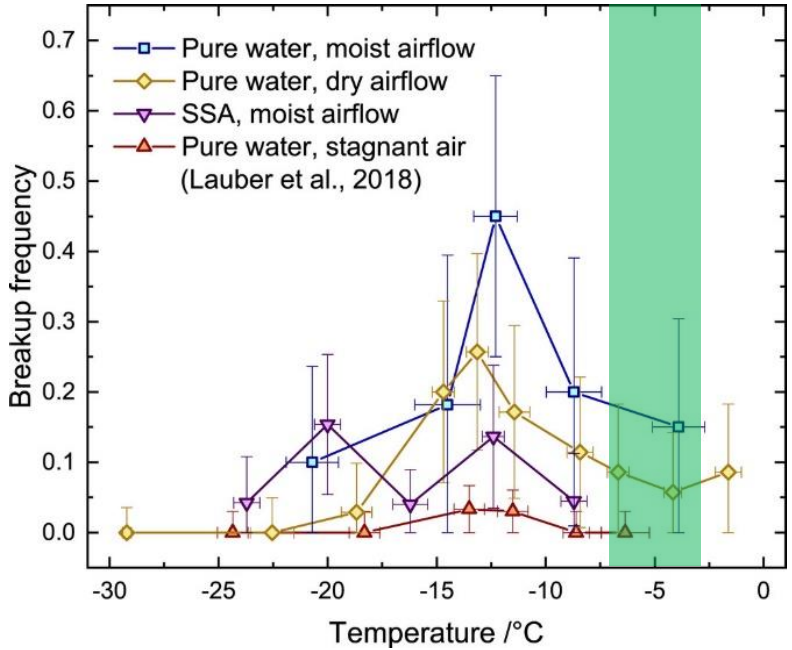
- Secondary production – more processes – rates

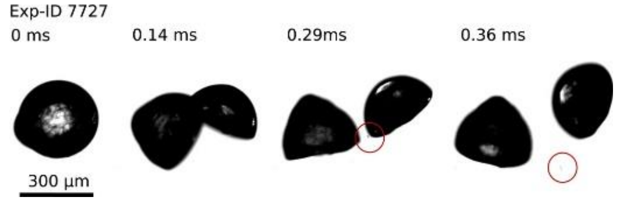


Hallett-Mossop rime splintering



Heymsfield and Mossop JAS 1984





Keinert et al. JAS 2020

Southern Ocean, **Outgoing SW**, Ice Nucleating Particles dependence.

Ice nucleation

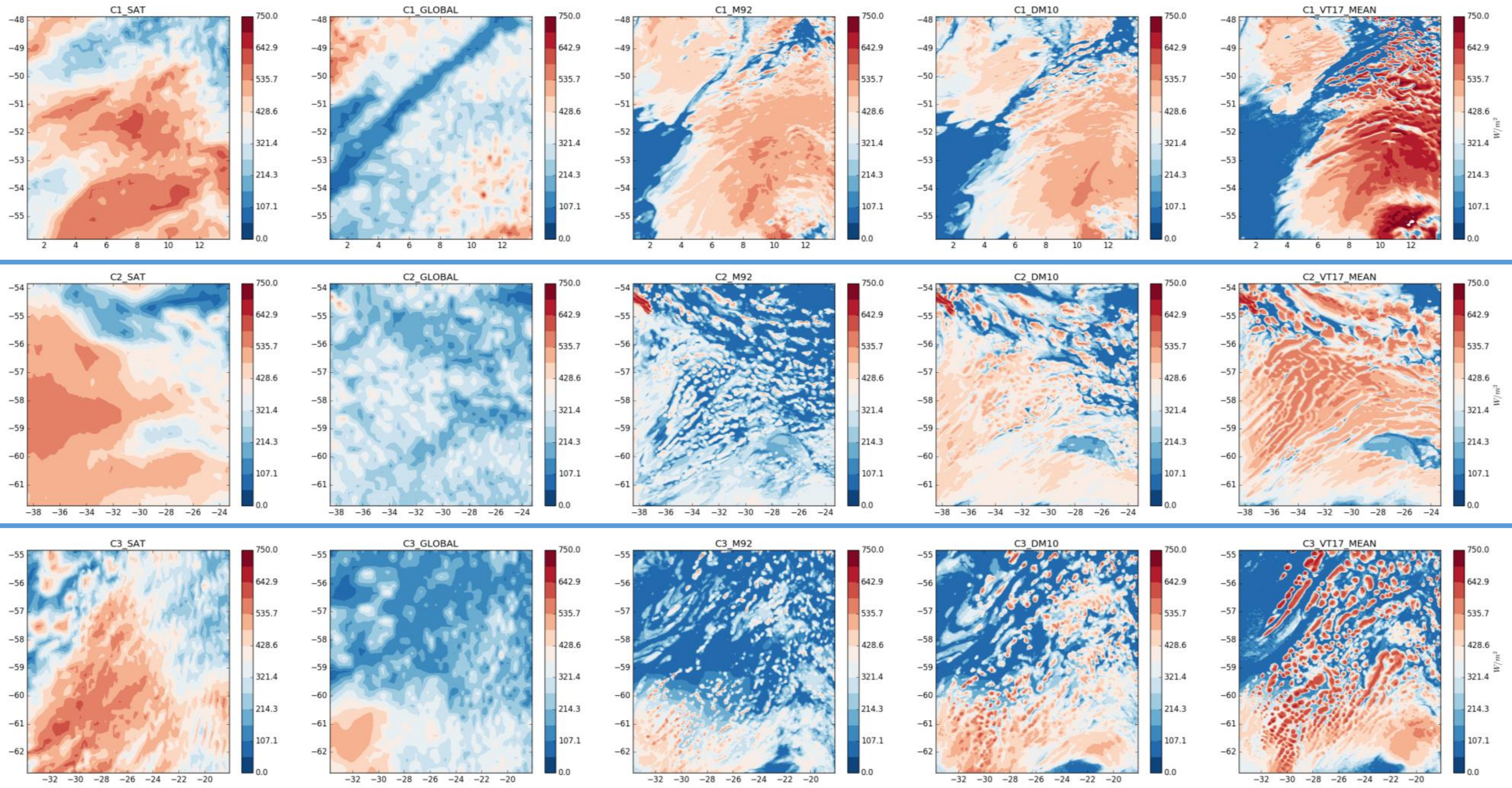
Regional (2km)

Satellite | Global (20km) | M92 | DM10 | VT17

case1

case2

case3

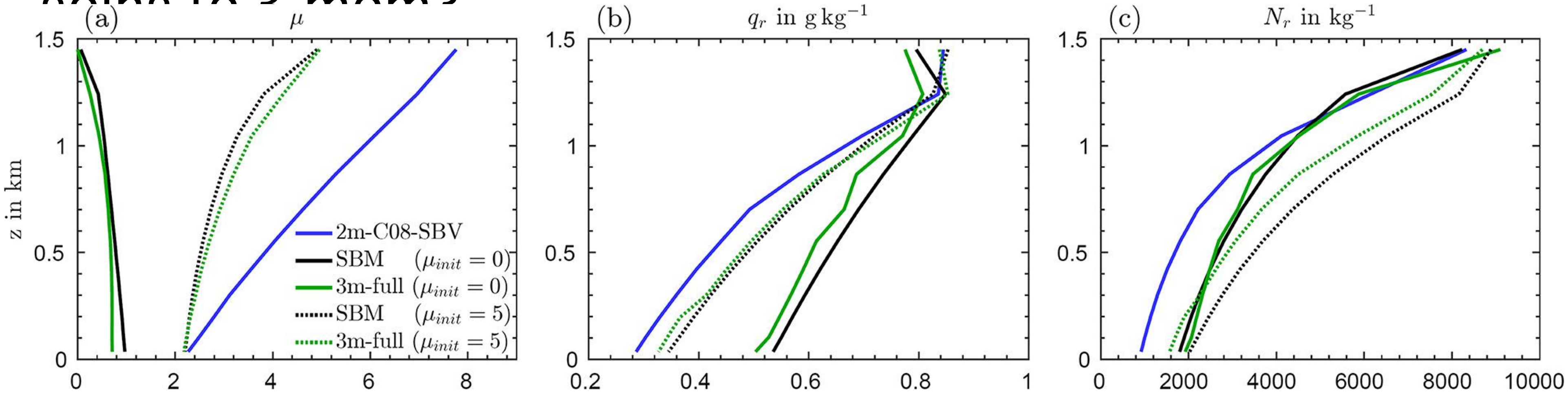


Decreasing INP number concentration

Vergara-Temprado et al. PNAS

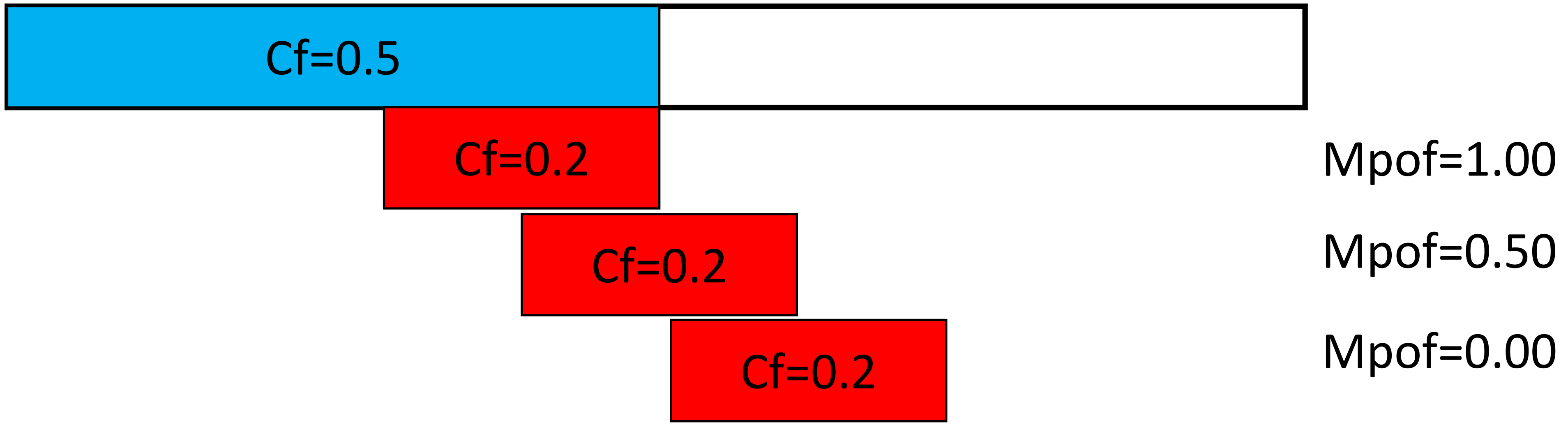
2 to 3 moments?

- 2-mom gives clear improvement over 1-mom precip histogram – is it worth going to 3-mom?



Paukert et al. 2018 JAMES

Overlap of mixed-phase regions



Conclusions

- Relative to operational cloud microphysics (Single moment, Wilson and Ballard):

  CASIM has less intense precipitation and more lighter precipitation

  CASIM convective cell sizes are smaller

  CASIM improves deficiencies raised in longstanding Operational Forecaster tickets

- CASIM+bimodal cloud scheme unifies the configuration for midlatitude and tropics – no requirement for separate M/T configurations

- More degrees of freedom brings requirement to constrain more process rates/parameters

- CASIM is the new double moment microphysics accepted for use in the next operational regional configuration (RAL3).