1D-Var Assimilation of Passive Microwave Brightness Temperature (Tb) in Rainy Atmospheres: Preliminary Results

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Outline

- 1D-Var Tb & 1D-Var SRR Methodology
- DMSP SSM/I and TRMM TMI Tb
- Tb dependence on surface rain rate (SRR)
- Tb jacobians (LWC,IWC, Rain Flux, Snow Flux- RTTOVSCATT)
- Comparison of simulated (GEM mesoglobal) and observed Tb (SSM/I) for Tropical Cyclone Zoe
- Surface rain rate retrievals and errors
- Results of 1D-Var Tb analyses for Tropical Cyclone Zoe and Super-typhoon Mitag

Tb 1D-Var

Observation Operator
Tb=*H*(X)

T(z), Q(z) , {dT/dt, dQ/dt}

↓

X=[T,lnQ]

↓

**MOIST PHYSICS
(CONVECTION &
LARGE-SCALE CLOUD SCHEMES)**

↓

**LIQUID AND ICE WATER CONTENTS (z),
RAIN FLUX (z), SNOW FLUX (z),
CLOUD FRACTION (z)**

↓

**Brightness Temperatures
RTTOVSCATT
Eddington Approximation
(Bauer & Moreau ECMWF)**

**Observed Tb FROM:
SSM/I, TMI
SSMIS, AMSR-E,
EGPM, GPM**

**Convection Scheme:
Kain-Fritsch (or ECMWF Mass-Flux)
Large-scale cloud scheme:
CLOUDST-Tompkins & Janiskova 2003
ECMWF**

Jacobians:
RTTOVSCATT: Adjoint
Cloud Schemes: Finite Difference

SRR 1D-Var

Observation operator
SRR=*H*(X)

T(z), Q(z),{dT/dt, dQ/dt)

↓

X=[T,lnQ]

↓

MOIST PHYSICS (CONVECTION & LARGE-SCALE CLOUD SCHEMES)

↓

SRR=SURFACE RAIN RATE

Observed Surface Rain Rate from:
SSM/I, TMI/PR
SSMIS, AMSR-E,
EGPM/NPR, GPM/PR

Convection Scheme:
Kain-Fritsch (or ECMWF Mass-Flux)
Large-scale cloud scheme:
CLOUDST-Tompkins & Janiskova 2003 (or COND)

Jacobians:
Cloud Schemes: Finite Difference

ASSIMILATING Tb or SRR?

Pros of assimilating Tb's instead of SRR

•Raw observations—easier to specify observation error
•SRR retrievals strongly algorithm dependent.
Tb is an indirect measurement of SRR.
•Can create rain even if background field is zero.
Tb sensitive to all hydrometeors (e.g. retrieve IWV in non-rainy atmospheres).

Cons of assimilating Tb's instead of SRR

•Need a more sophisticated observation operator to model cloud and precipitation profiles.

BACKGROUND TERM

GEM MESOGLOBAL CONFIGURATION

- GLOBAL MODEL: 800 (longitude) x 600 (latitude)
  - 0.45^ox 0.3^o grid resolution
- 58 vertical levels (top at 10 hPa)
- Time-step= 15 minutes
- Kain-Fritsch (CAPE) and CONSUN (Sundqvist variant)
- 12h precipitation spin-up

1D-Var Background = 12h forecast

Background Errors

- Correlation of T and lnQ background errors from 24-48h forecasts of GEM mesoglobal (C. Charette)
- σ_T=1 K
- σ_Q computed from empirical formula as done at ECMWF (Rabier et al. 1998) & $\sigma_{lnQ} = \sigma_Q / Q$

SSM/I Channel Summary

FREQUENCY (GHz)	RESOLUTION (km)
19V	70x45
19H	70x45
22V	60x40
37V	38x30
37H	38x30
85V	16x14
85H	16x14

Nominal Resolution:
25 km @ 19,22 and 37 GHz
12.5 km @ 85 GHz

F13, F14, F15
Conical Scan
Swath 1400 km
Sun-synchronous
Inclination 98°
Height 830 km

TMI Channel Summary

FREQUENCY (GHz)	RESOLUTION (km)
11V	63x37
11H	63x37
19V	30x18
19H	30x18
21V	23x18
37V	16x9
37H	16x9
85V	7x5
85H	5x5

Nominal Resolution:

10 km @ 11, 29, 21,37 GHz

5 Km @ 85.5 GHz

Conical scan

Height 400 km

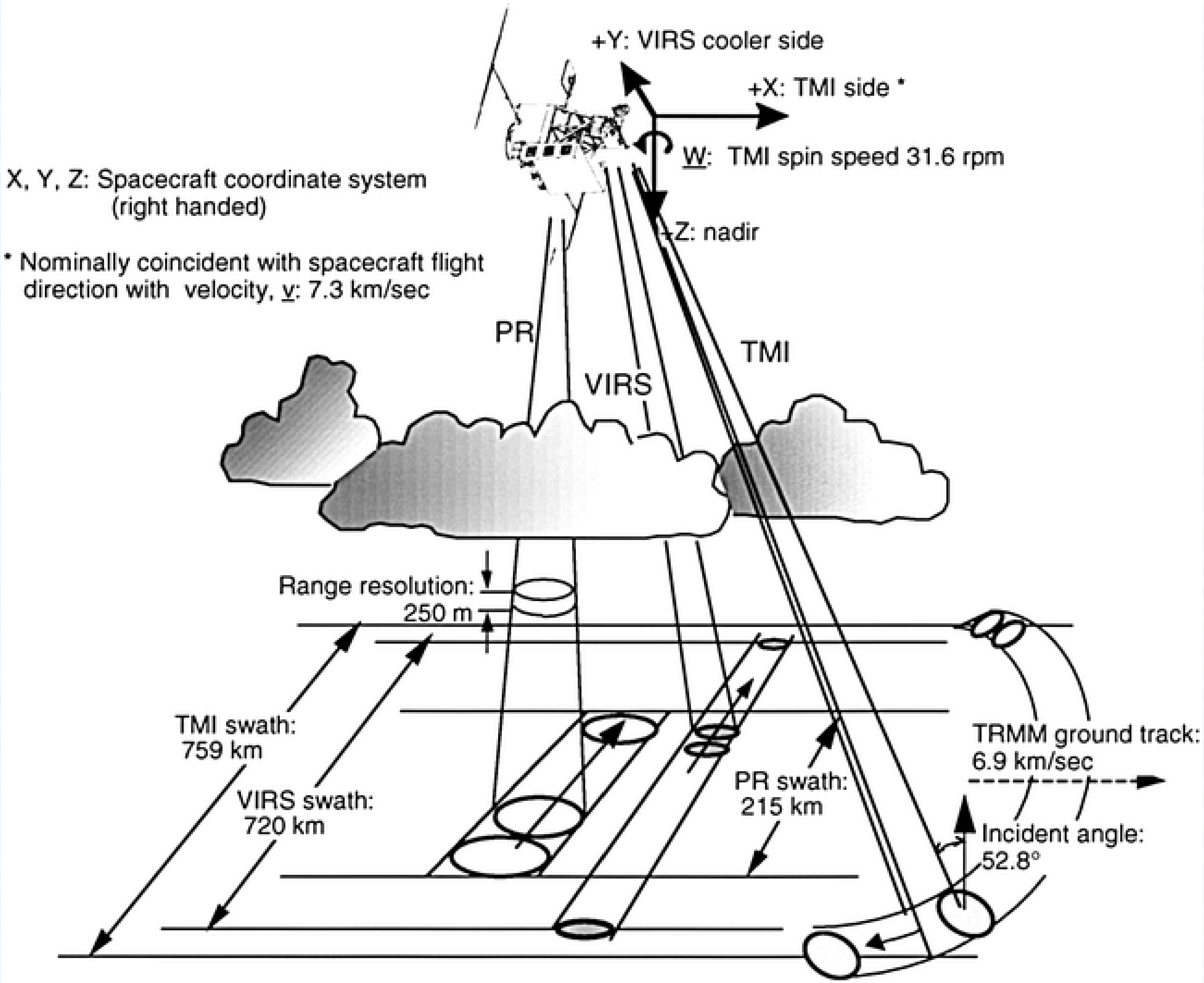
Inclination 35^{o}

Not Sun-Synchronous

Swath 760 km

Circular orbit

Schematic view of the scan geometries of the three TRMM primary rainfall sensors: TMI, PR, and VIRS.



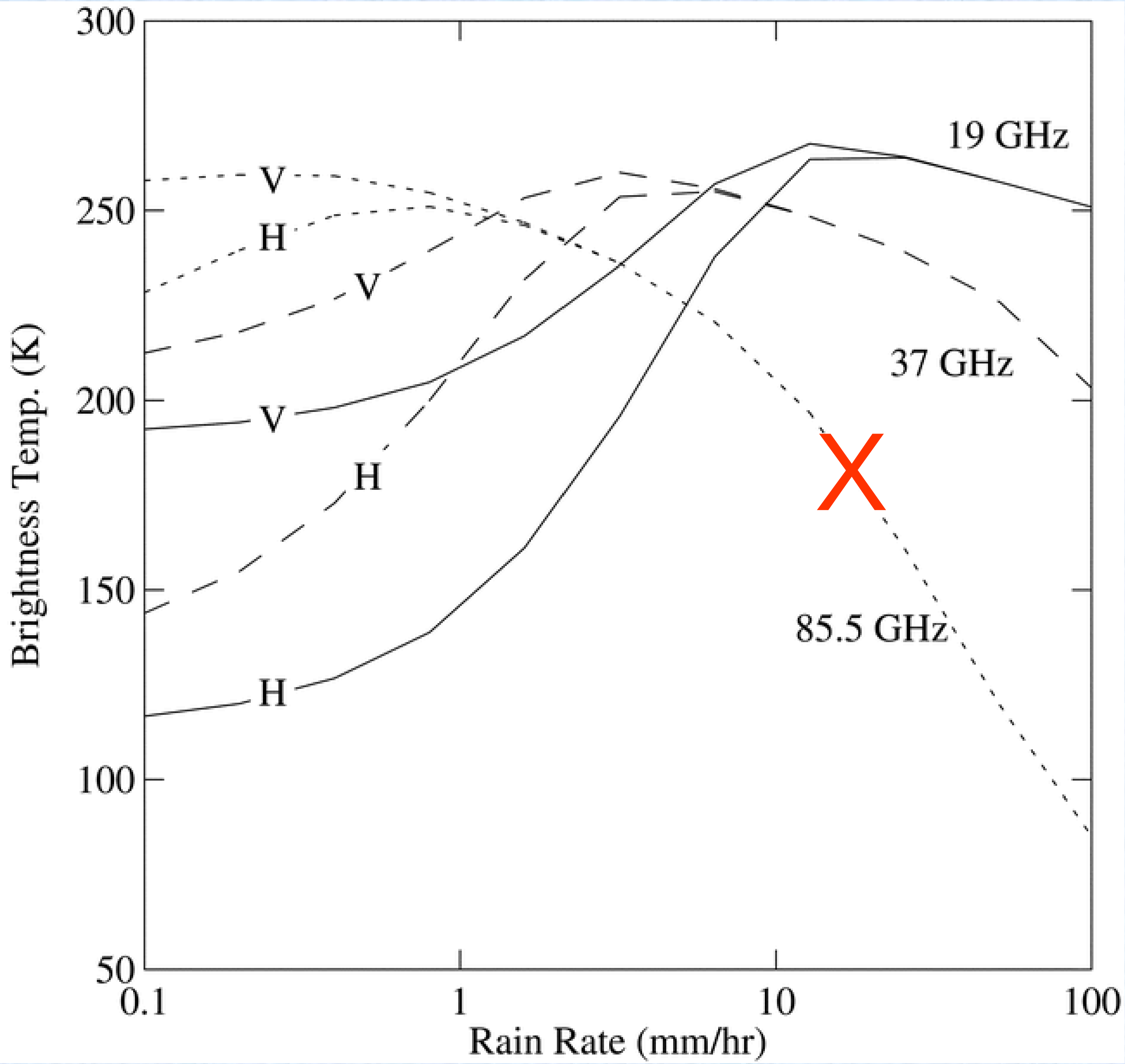
PR= Precipitation Radar

13.8 GHz

Resolution=4x4 km

Kummerow & al. 1998 JAOT

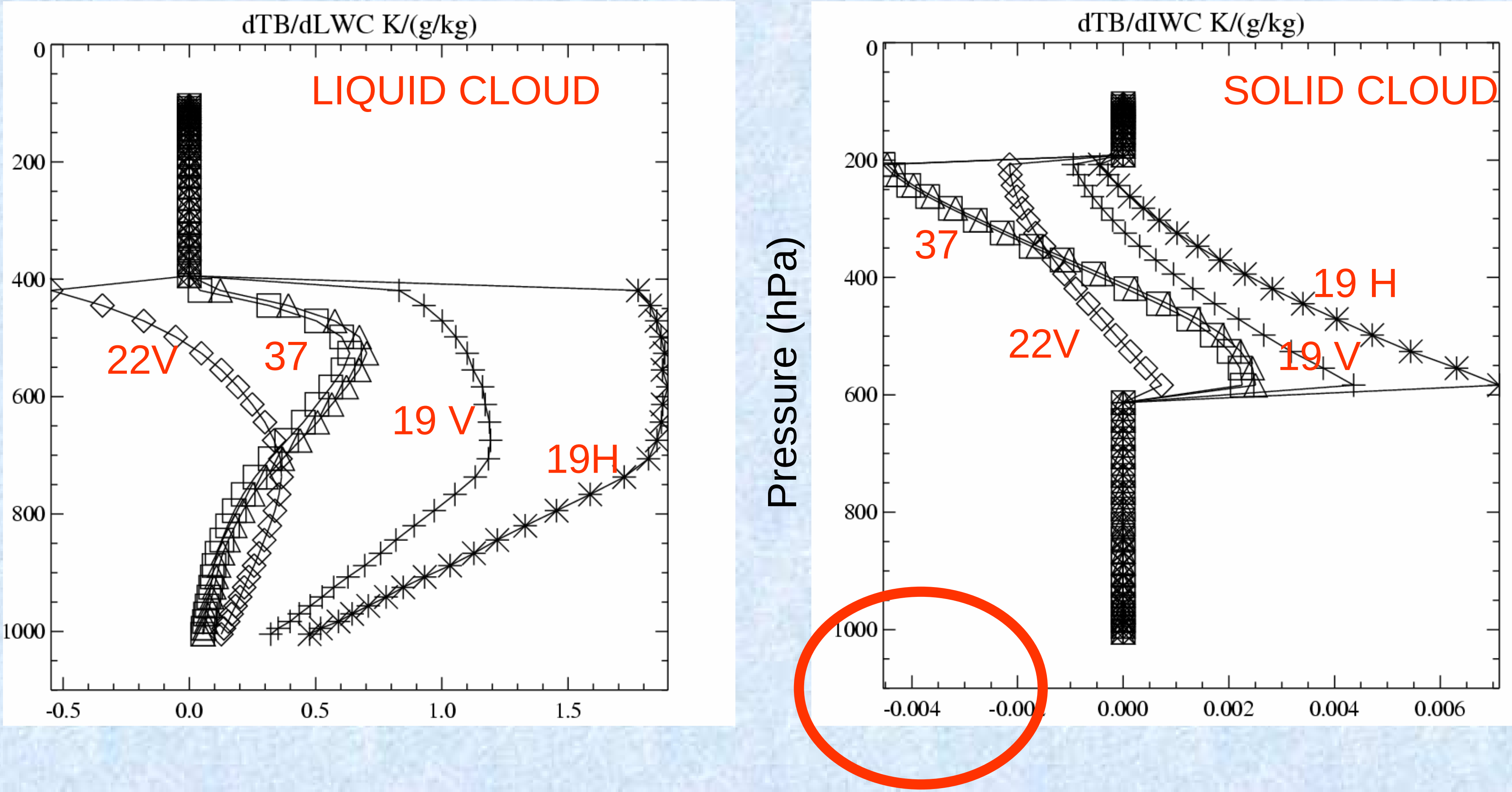
Idealized brightness temperature dependence on surface rain rate (SRR)



Petty 2001 JAM

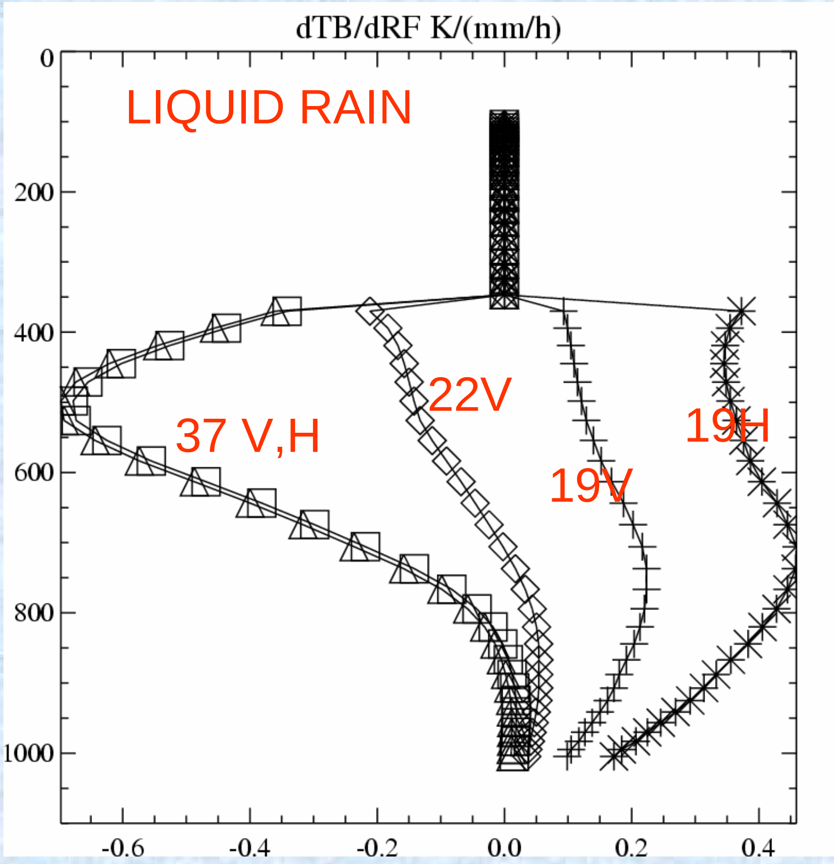
Brightness Temperature Jacobians

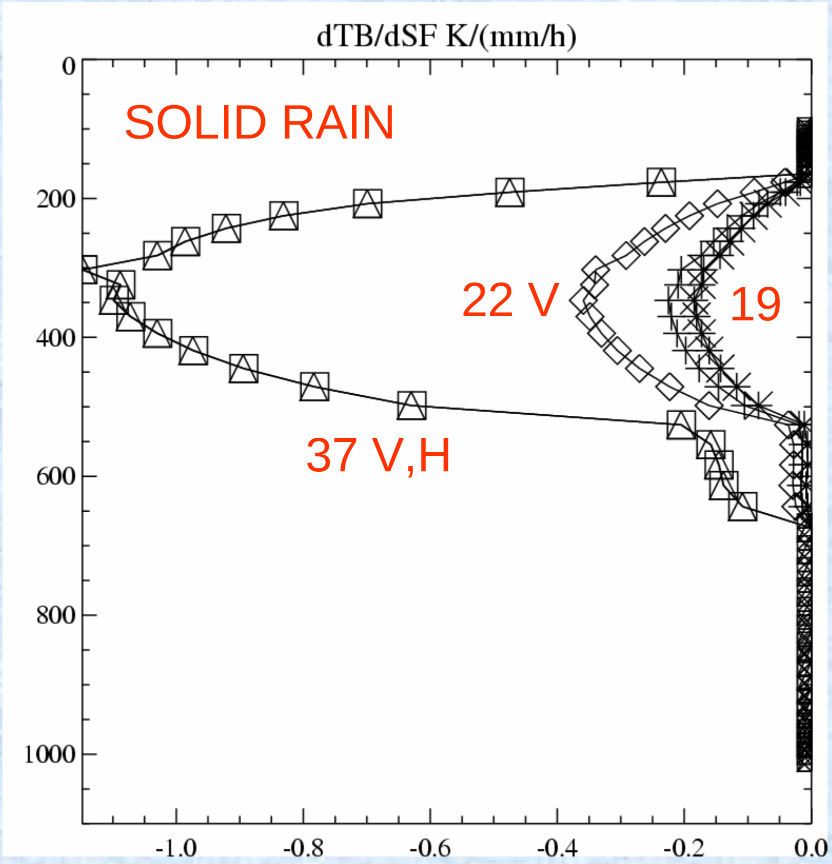
RTTOVSCATT **Eddington Approx. Kummerow 1993 JGR; FASTEM2**
Hurricane Juan; 12h forecast started at 2003 09 27 1200 UTC



First Guess IWV=57.63 kgm^{-2}, LWP=2.28 kgm^{-2} , SRR=3.69 mmh^{-1}

Brightness Temperature Jacobians
Continued…



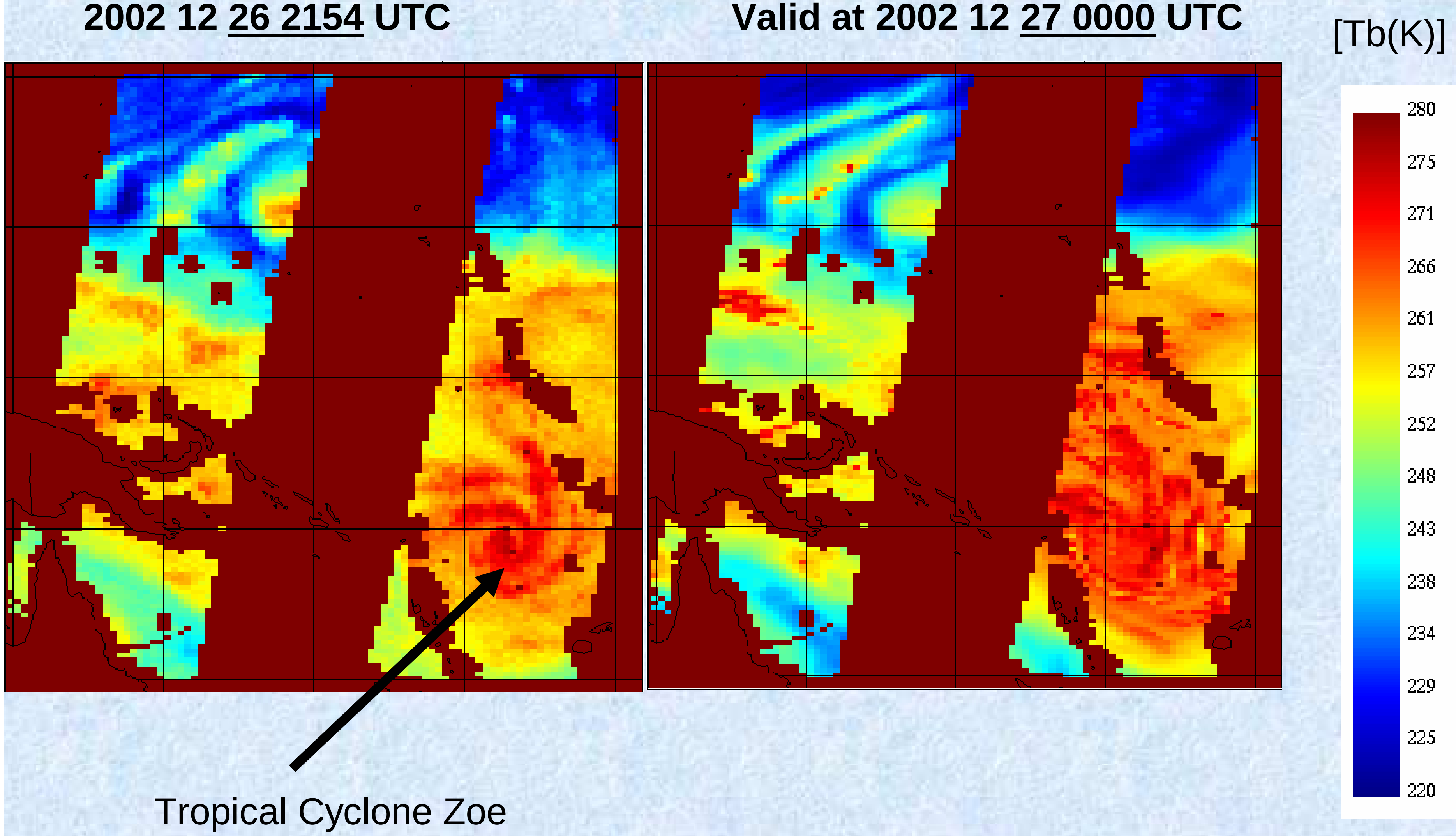


First Guess IWV=57.63 kgm^{-2}, LWP=2.28 kgm^{-2} , SRR=3.69 mmh^{-1}

Brightness Temperature 22 GHz V

SSM/I OBSERVATIONS
Nearest Neighbor to Model Grid
2002 12 26 2154 UTC

Mesoglobal 12h FORECAST
800x600 grid
Valid at 2002 12 27 0000 UTC

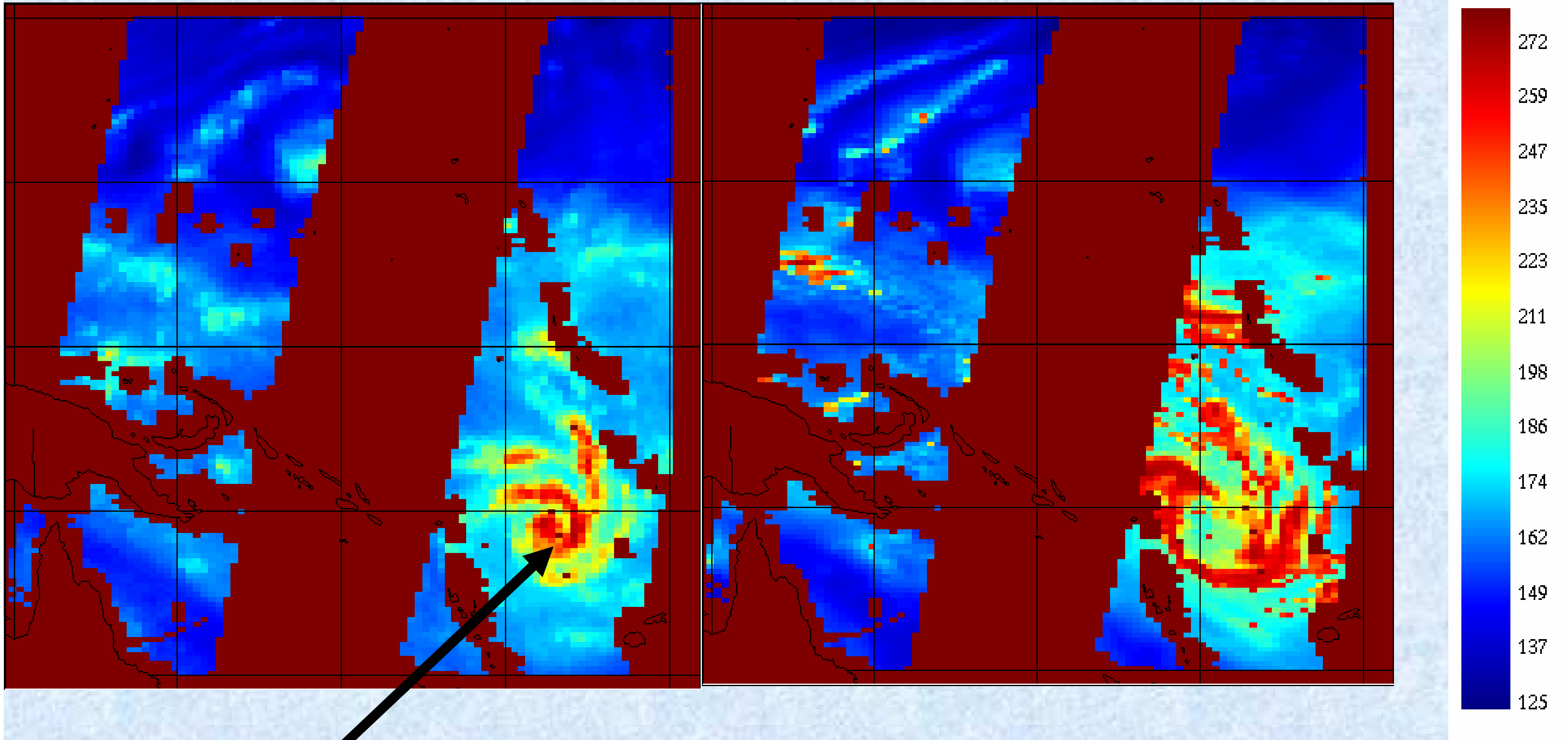


Brightness Temperature 19 GHz H

SSM/I OBSERVATIONS
Nearest Neighbor to Model Grid
2002 12 26 2154 UTC

Mesoglobal 12h FORECAST
800x600 grid
Valid at 2002 12 27 0000 UTC

[Tb(K)]



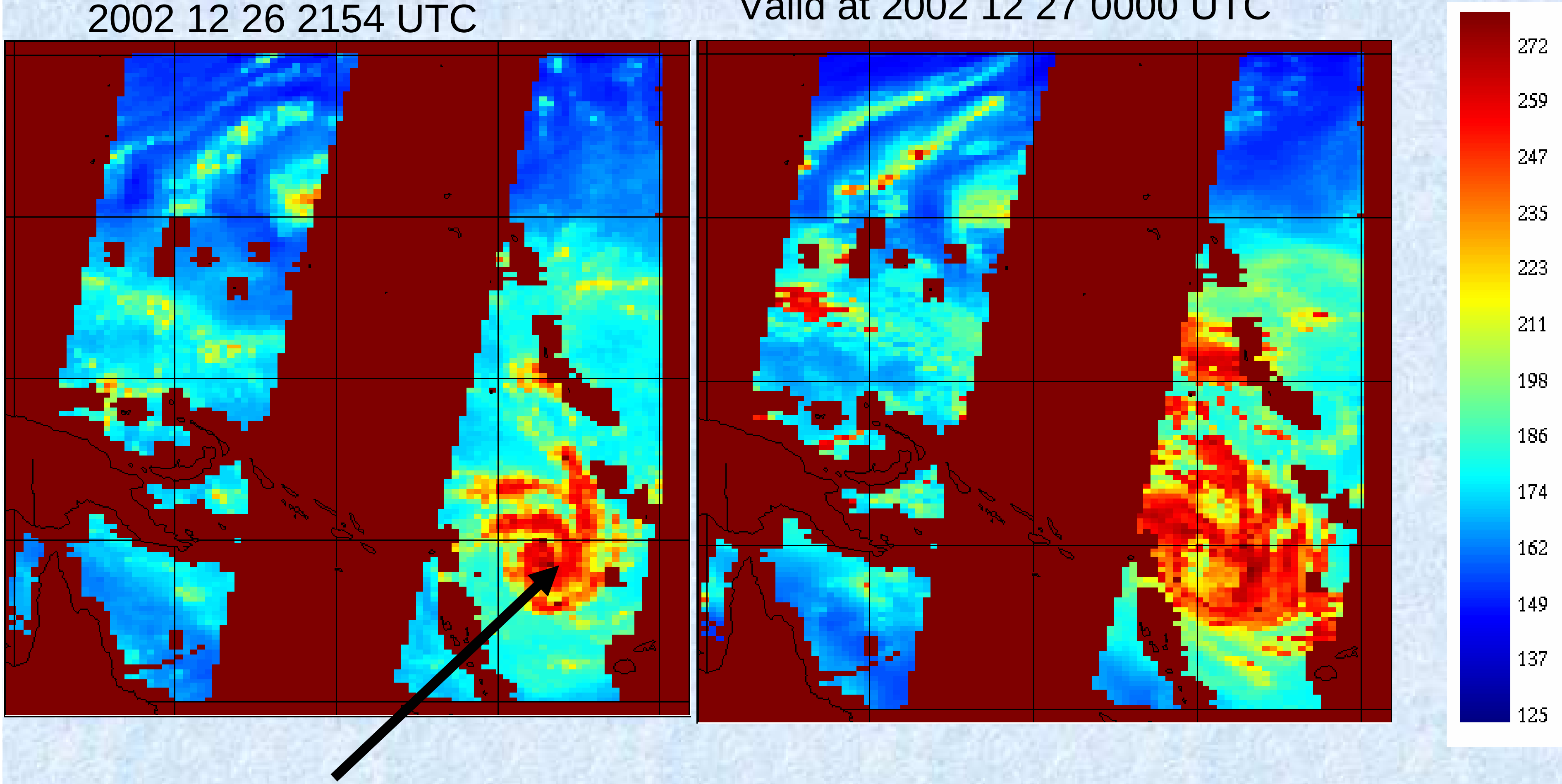
Tropical Cyclone Zoe

Brightness Temperature 37 GHz H

SSM/I OBSERVATIONS
Nearest Neighbor to Model Grid
2002 12 26 2154 UTC

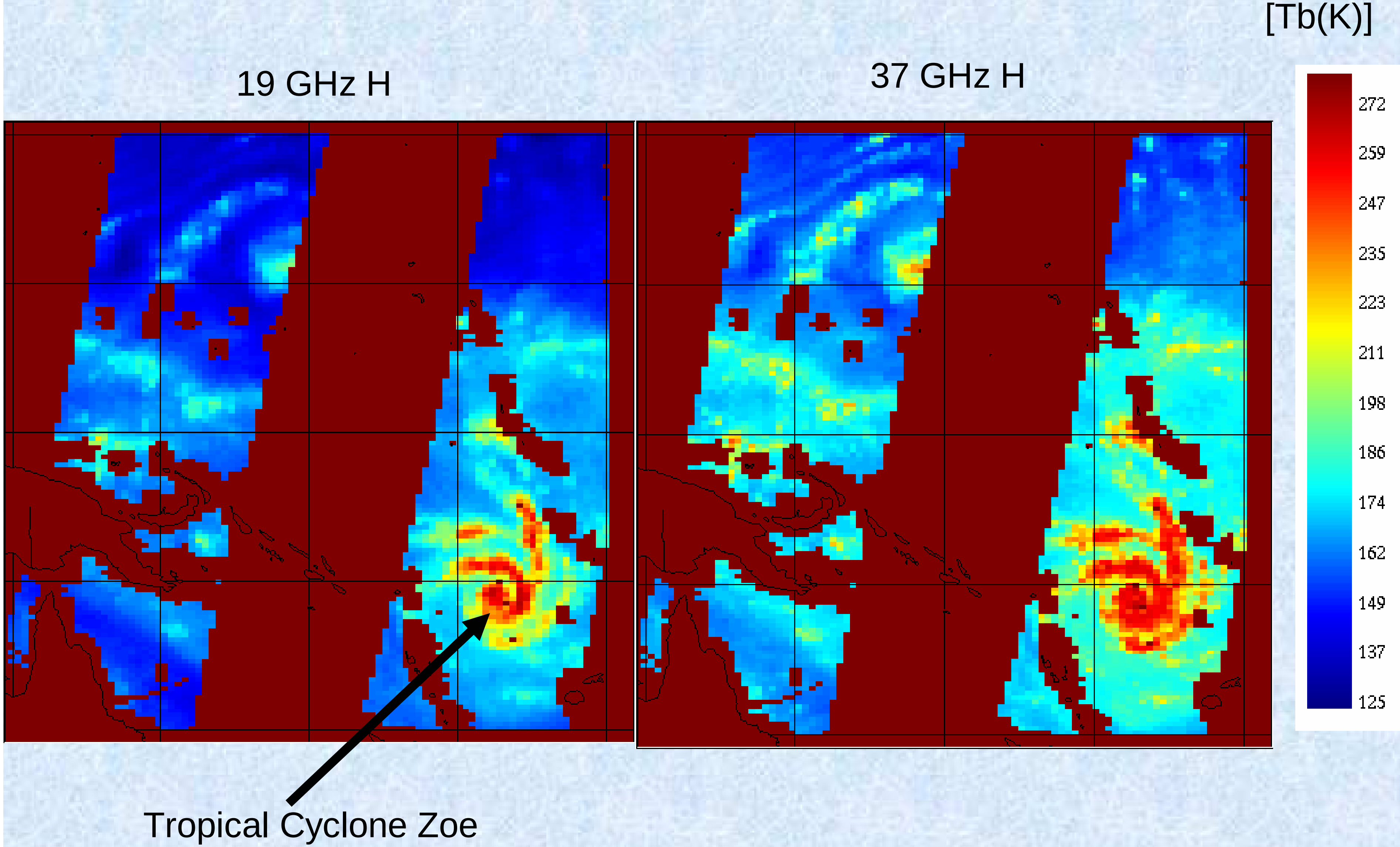
Mesoglobal 12h FORECAST
800x600 grid
Valid at 2002 12 27 0000 UTC

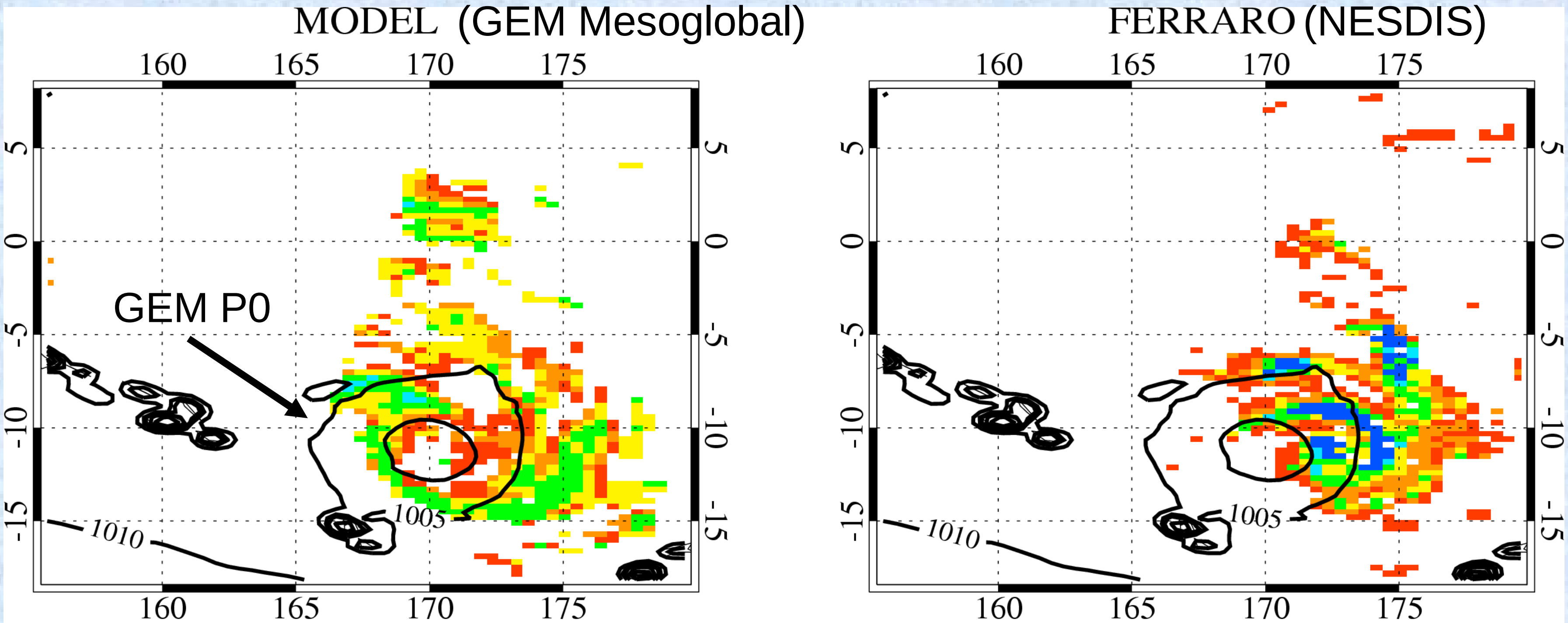
[Tb(K)]

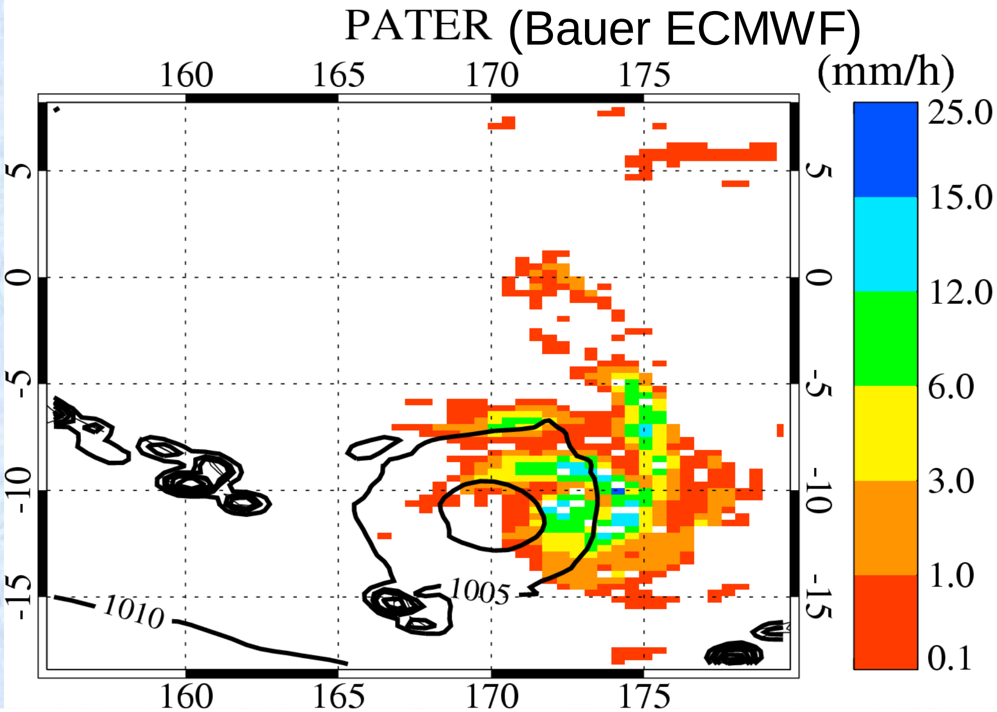


Tropical Cyclone Zoe

Brightness Temperature SSM/I
Nearest Neighbor to Model Grid
2002 12 26 2154 UTC





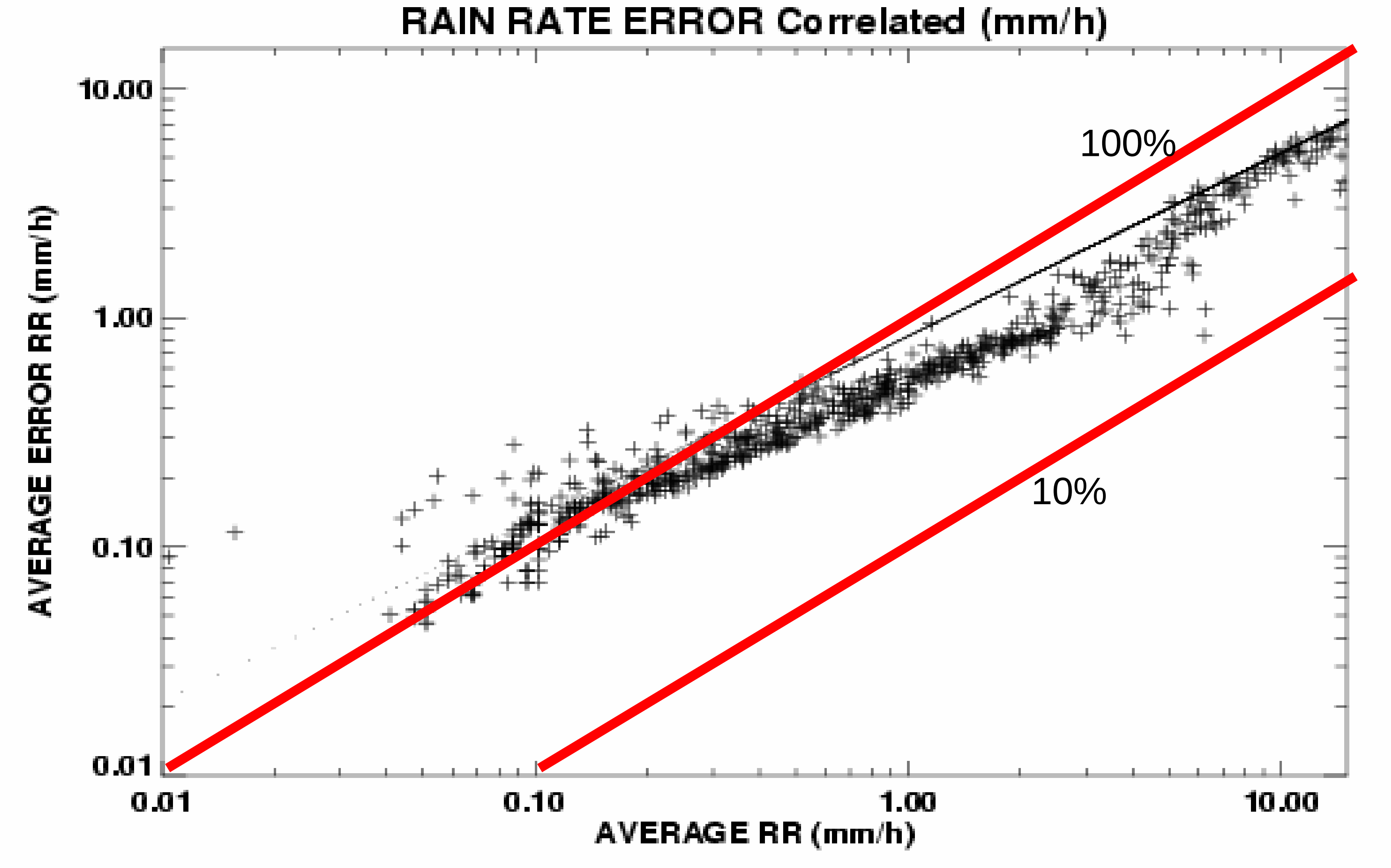


R=-0.23 (>0.1 mm/h) mod vs obs 1

R= 0.87 (>0.1 mm/h) obs 1 vs obs 2

SURFACE RAIN RATE
TROPICAL CYCLONE ZOE
2002 12 27 0000 UTC

ZOE SSM/I **SRR** (PATER CAL) AVERAGED TO GEM MESOGLOBAL GRID



PATER= Precipitation Radar (PR) adjusted TMI estimation of rainfall)

1D-Var Tb: process rainy profiles only

Choice of profiles:

IF (1D-Var BACKGROUND SRR ≤ 1.e-4 mmh^{-1} AND TB37V-TB37H ≥ 40. K)

REJECT PROFILE

$$P \equiv \frac{Tb_{37V} - Tb_{37H}}{Tb_{37Vclear} - Tb_{37Hclear}}$$

$$P \cong \tau^2 \equiv e^{-2\sigma/\cos(\theta)}$$

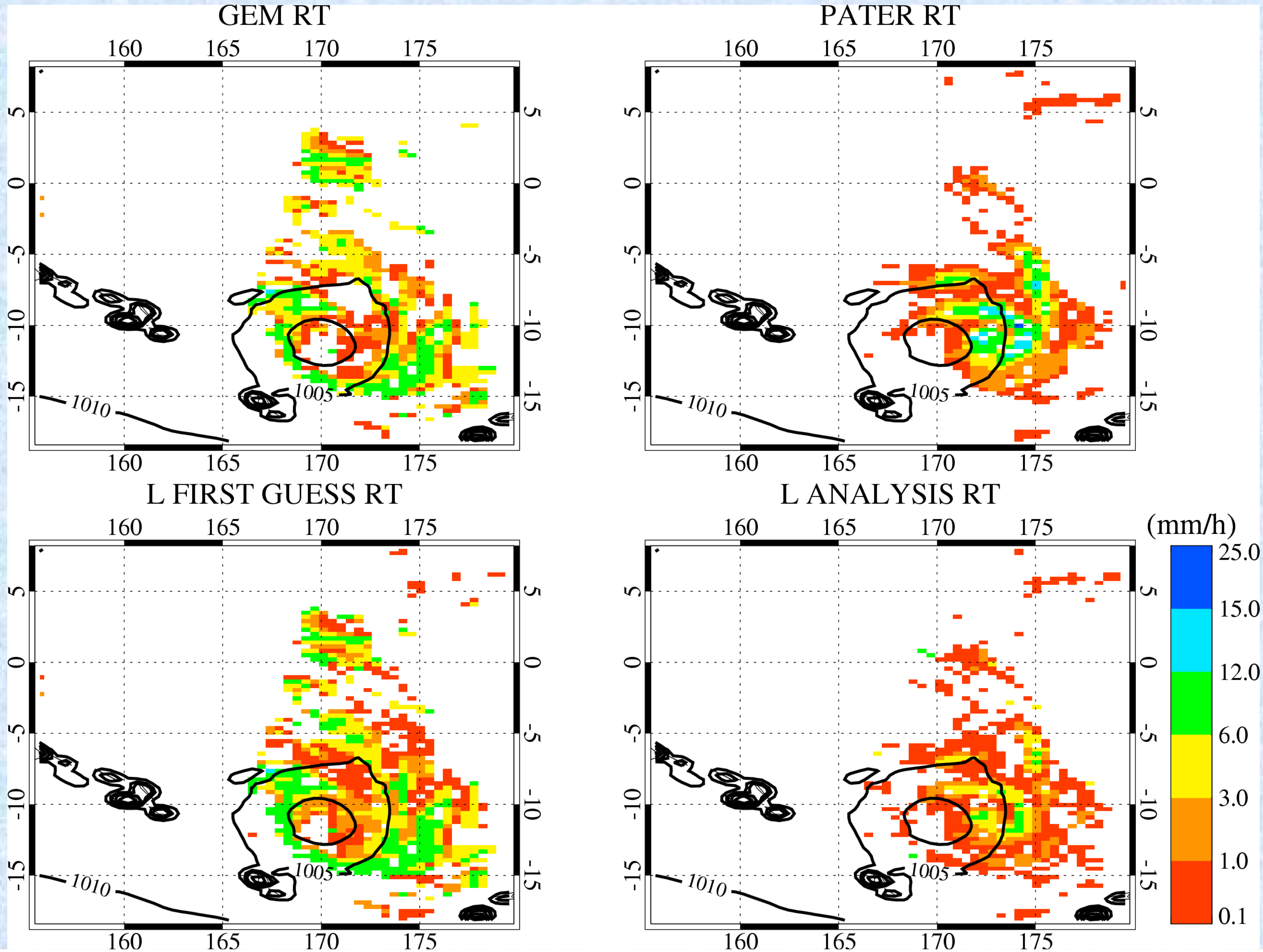
P is a measure of visibility of sea-surface relative to expected value in absence of clouds

P=0 => completely opaque rain cloud

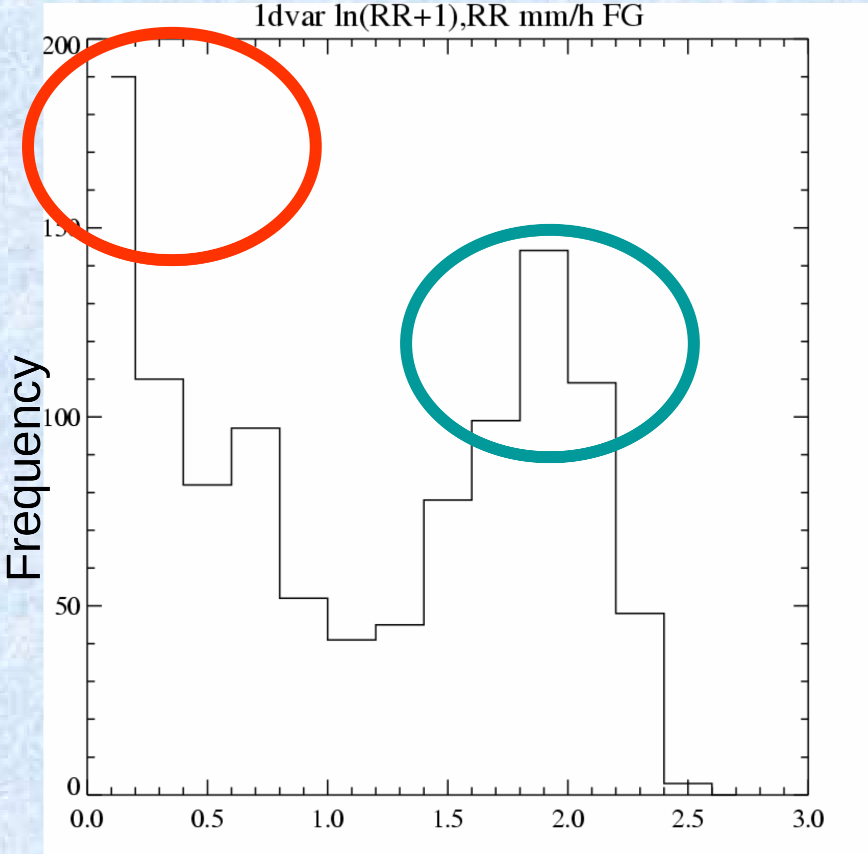
P=1 => cloud-free ocean scene

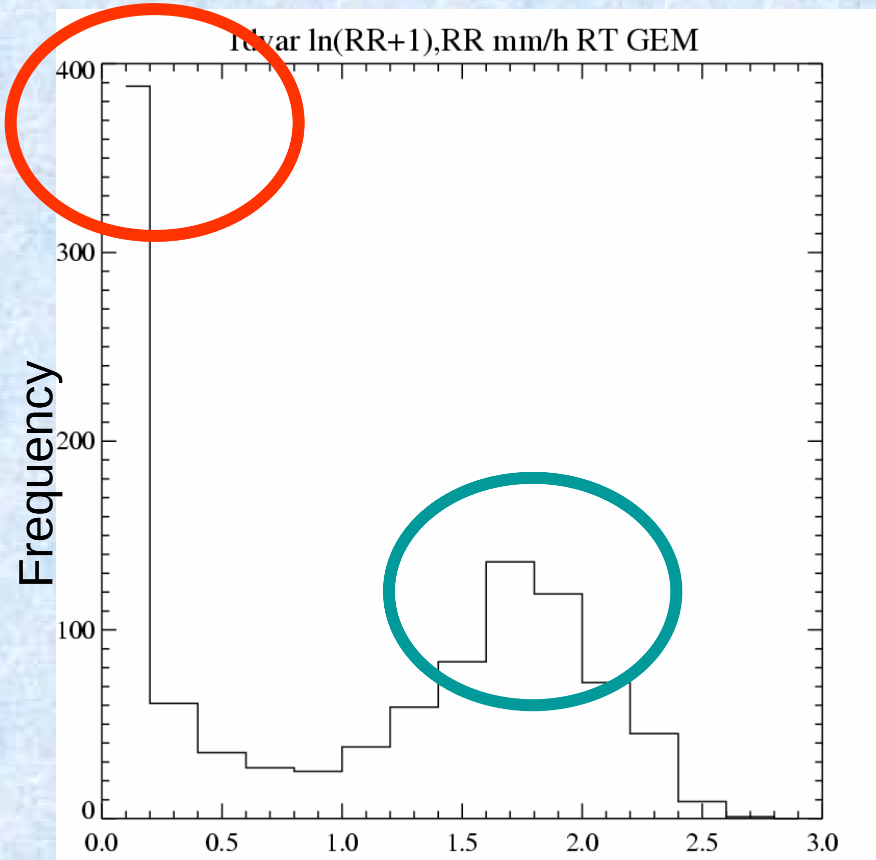
If P > 0.15 (τ > 0.4) then use 37 GHz channels (total of 5/SSM/I and 7/TMI)

TROPICAL CYCLONE ZOE Valid at 2002 12 27 0000 UTC: SRR



TROPICAL CYCLONE ZOE Valid at 2002 12 27 0000 UTC: ln (SRR+1.0)
Assimilation of F15 SSM/I Tb





Ln (SRR+1.0)—**BACKGROUND**
Kain-Fritsch + Tompkins & Janiskova 2003

Ln (SRR+1.0)—**GEM**
Kain-Fritsch + CONSUN

TROPICAL CYCLONE ZOE 2002 12 27 0000UTC
(SSM/I KFTJ P=12h forecast)
profiles ok= 97.1%

BRIGHTNESS TEMPERATURE (K)

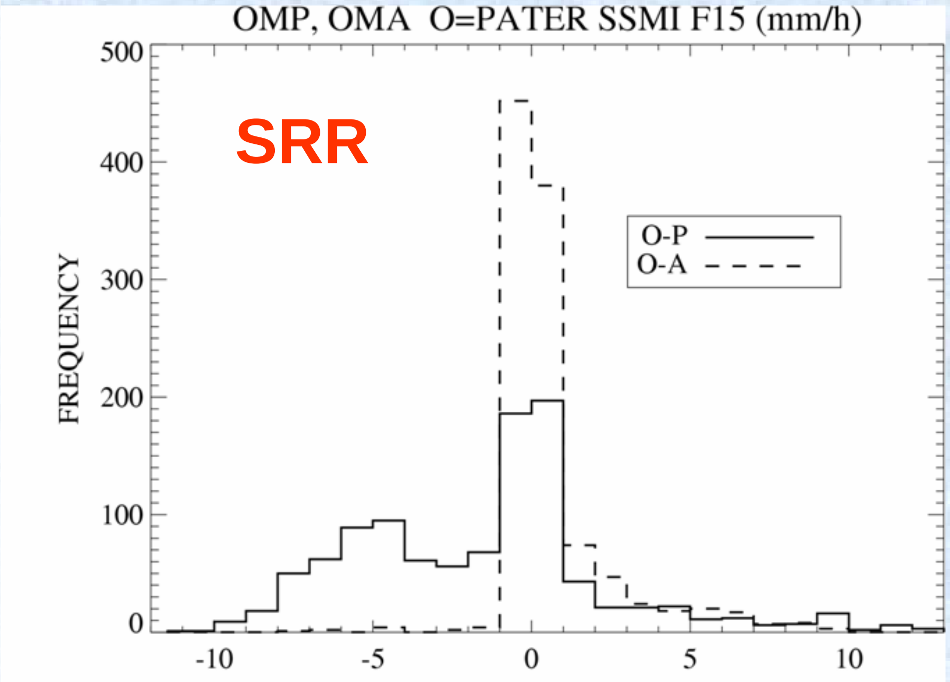
CHANNEL	**O-P**		**O-A**			**Tb obs.**
SSM/I	Bias	SD	Bias	SD	N	**Error (K)**
19V GHz	-16.0077	21.3028	-0.810110	3.10757	1098	3.0
19H GHz	-29.8413	41.2874	-0.507923	6.37171	1098	6.0
22V GHz	-4.61540	7.12777	-0.962842	2.18700	1098	3.0
37V GHz	-9.29548	16.2390	-2.95461	2.21589	531	3.0
37H GHz	-14.5554	33.1771	-2.17213	4.32112	531	6.0

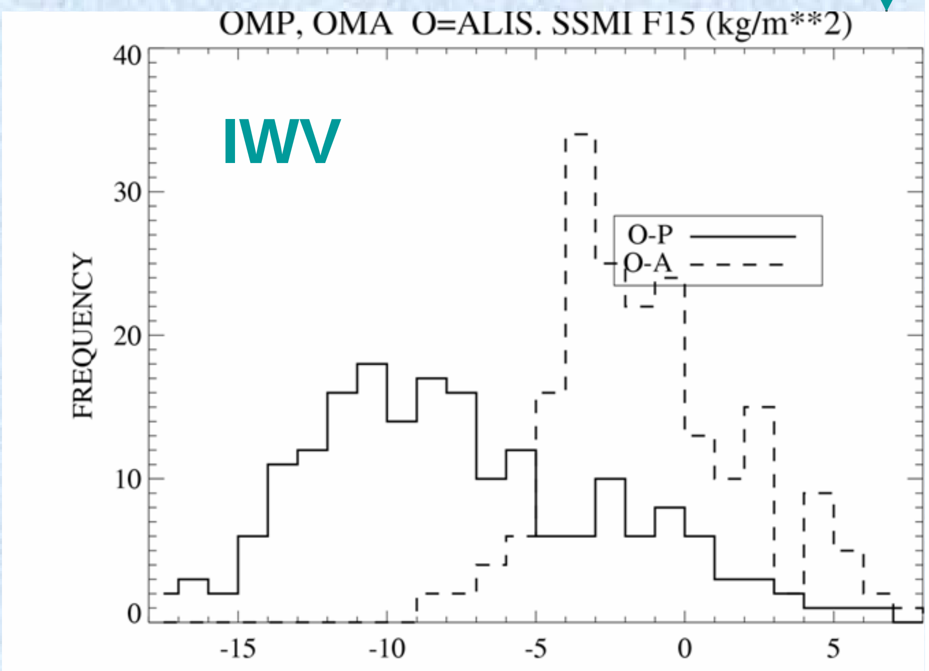
SSM/I Surface Rain Rate PATER CAL (mm/h)

O-P		O-A		
Bias	SD	Bias	SD	N
-1.53147	3.96483	0.749011	1.77818	1063

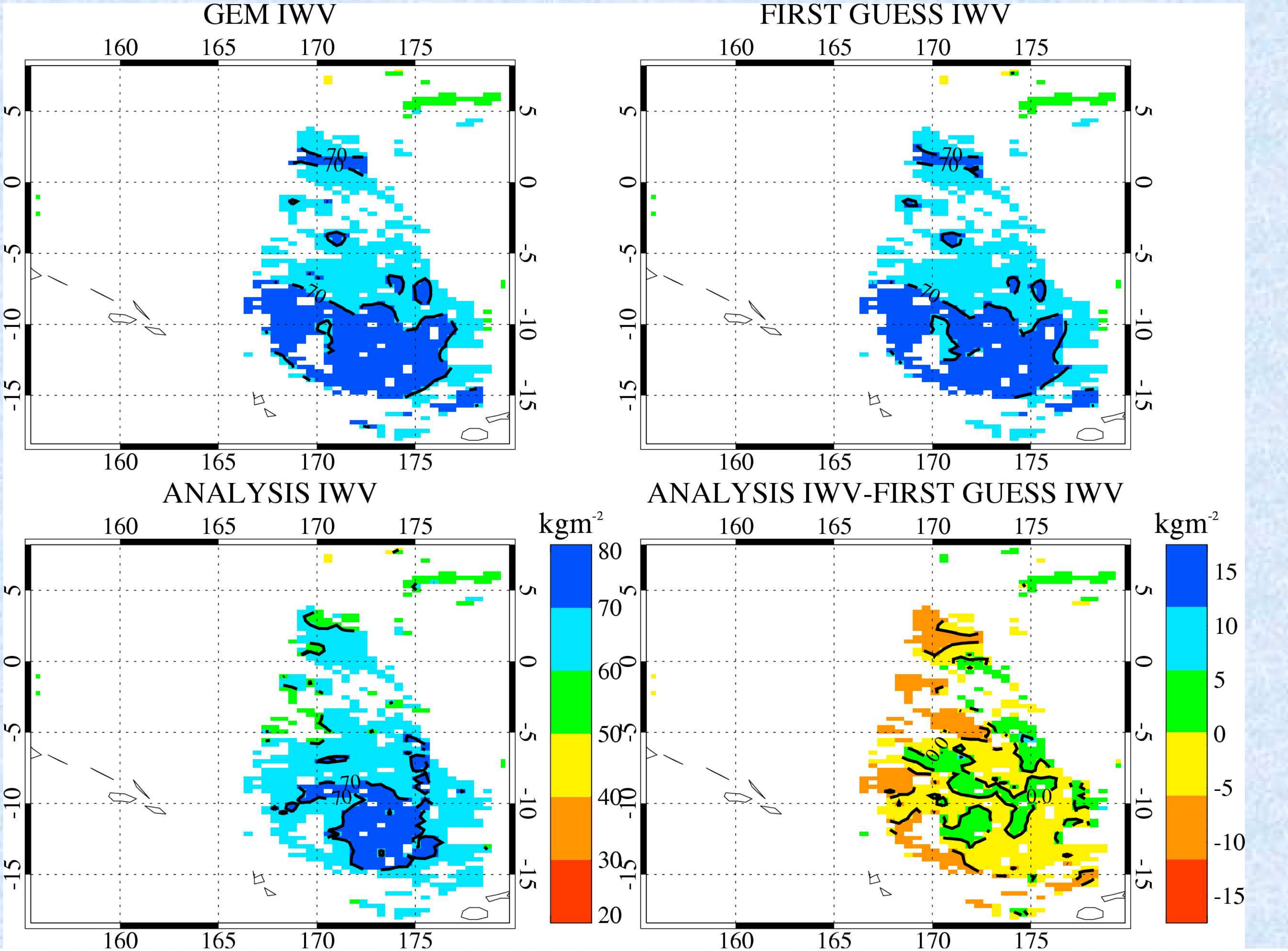
SSM/I Alishouse/Petty Integrated Water Vapor (kgm-2) No Precip in obs

O-P		O-A		
Bias	SD	Bias	SD	N
-7.54775	5.00135	-1.22411	3.11308	192



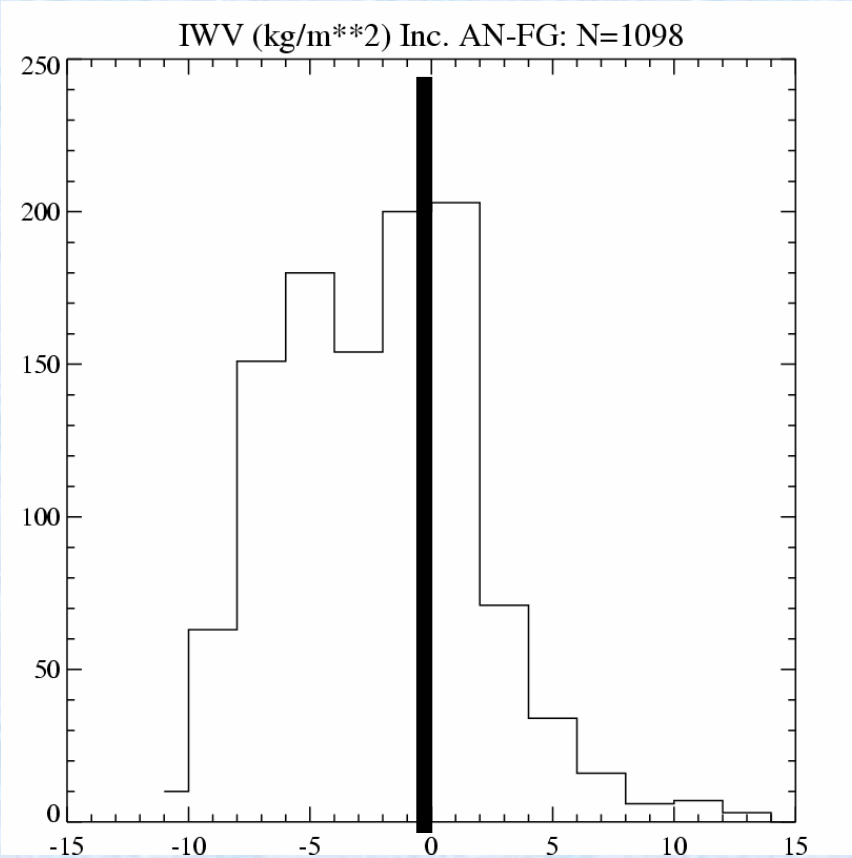


TROPICAL CYCLONE ZOE Valid at 2002 12 27 0000 UTC: IWV



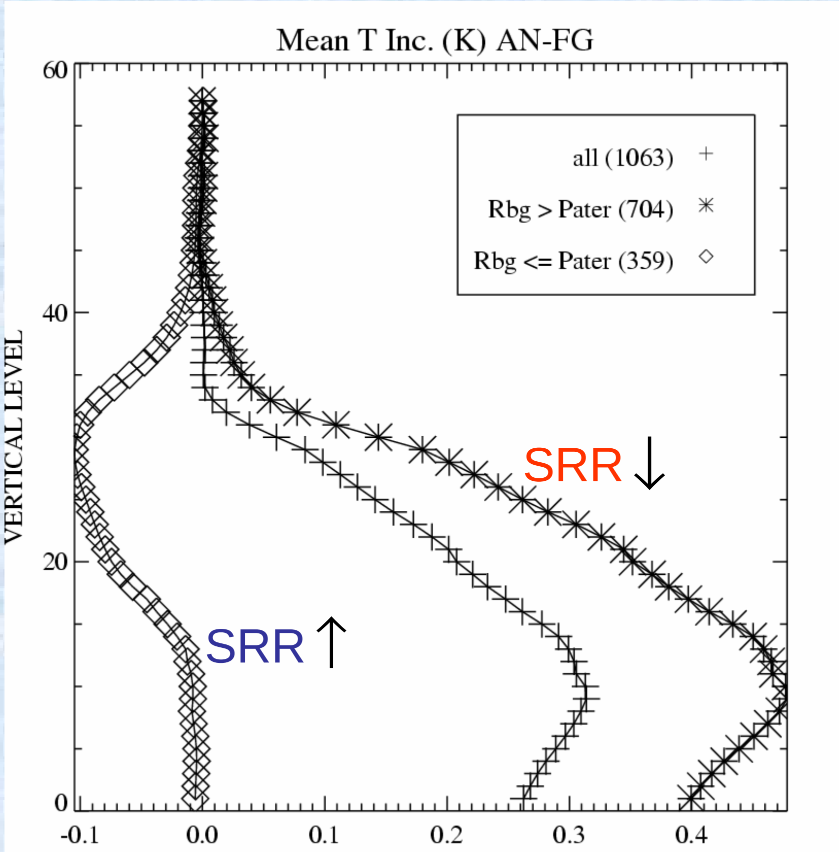
TROPICAL CYCLONE ZOE Valid at 2002 12 27 0000 UTC: IWV Inc. Assimilation of F15 SSM/I Tb

Frequency

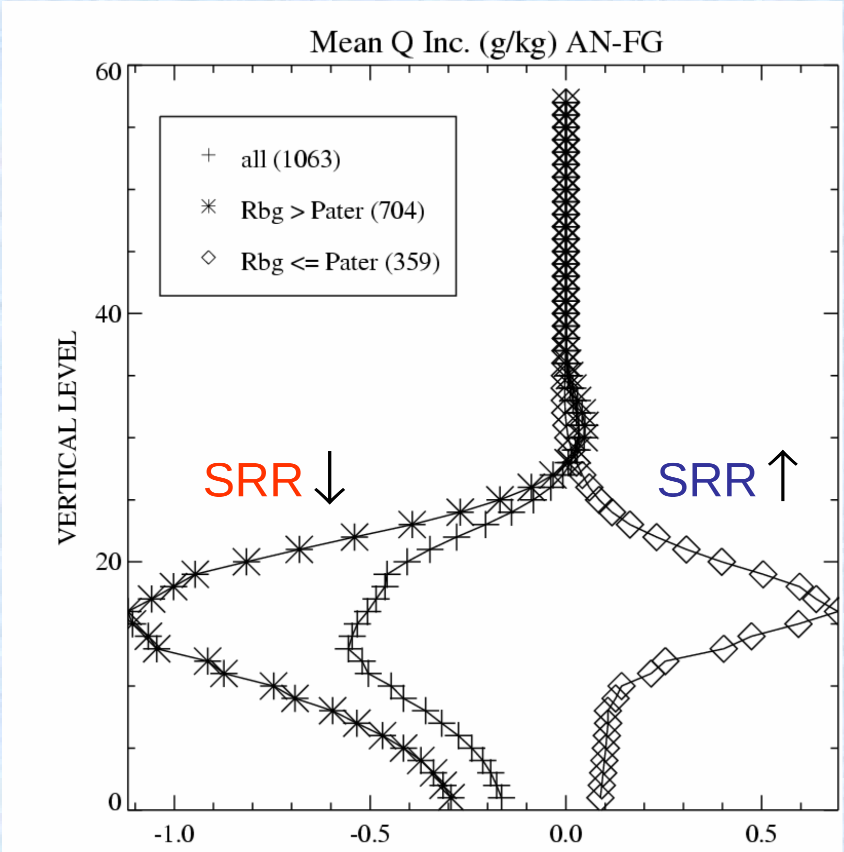


Integrated Water Vapor Increments (= Analysis-BACKGROUND) kgm^{-2}

TROPICAL CYCLONE ZOE Valid at 2002 12 27 0000 UTC: T and Q Inc.
Assimilation of F15 SSM/I Tb



Temperature increments (K)



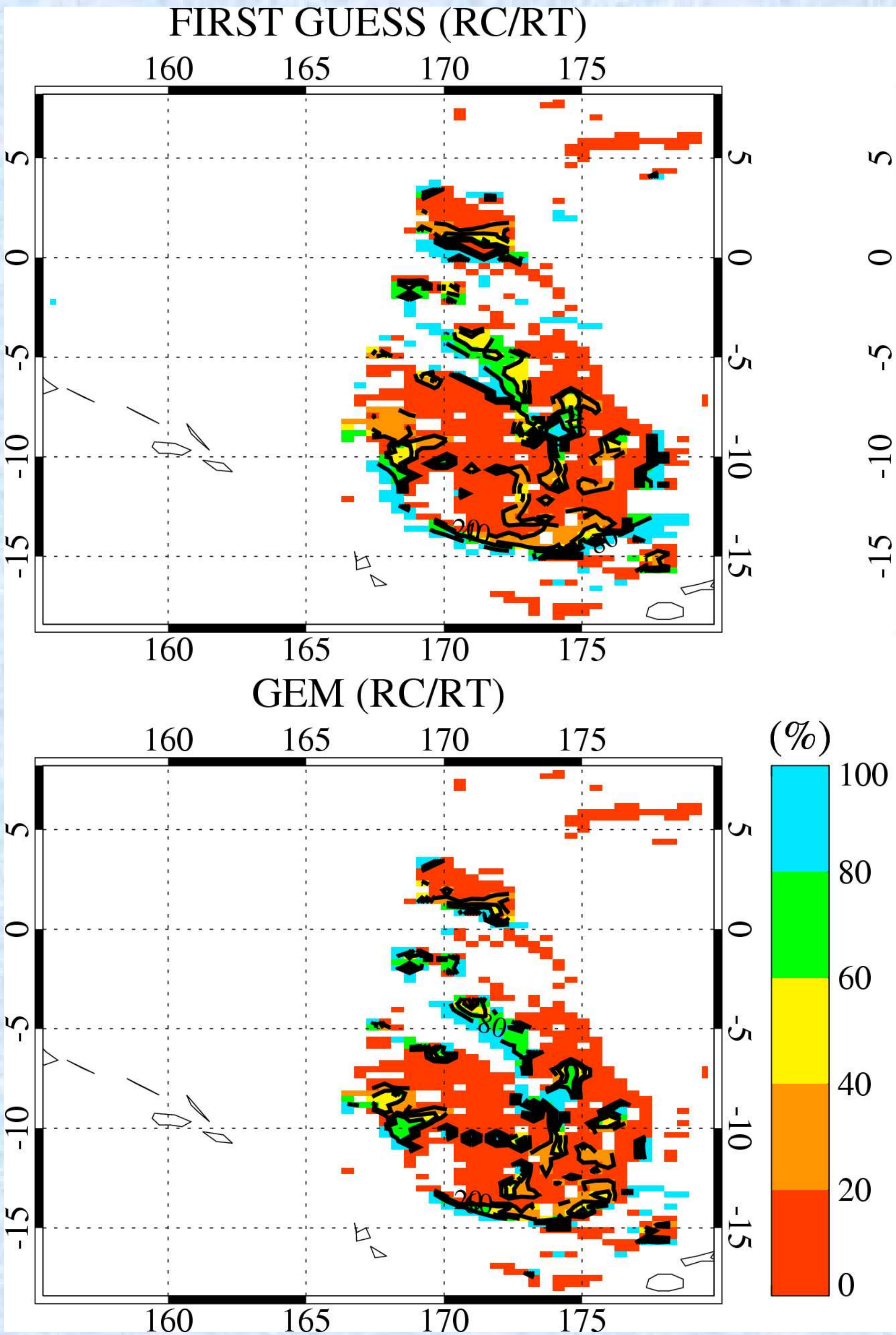
Specific Humidity increments (gkg^{-1})

Temperature Equivalent Change in Qsat (saturation specific humidity)

- Qsat(28.0C)-Qsat(27.0C)=1.37 g/kg
- Qsat(27.1C)-Qsat(27.0C)=0.13 g/kg
- Qsat(15.0C)-Qsat(14.0C)=0.67 g/kg
- Qsat(14.1C)-Qsat(14.0C)=0.065 g/kg

ECMWF: T increments ~0.1 K
MSC: T increments ~0.4-0.6 K

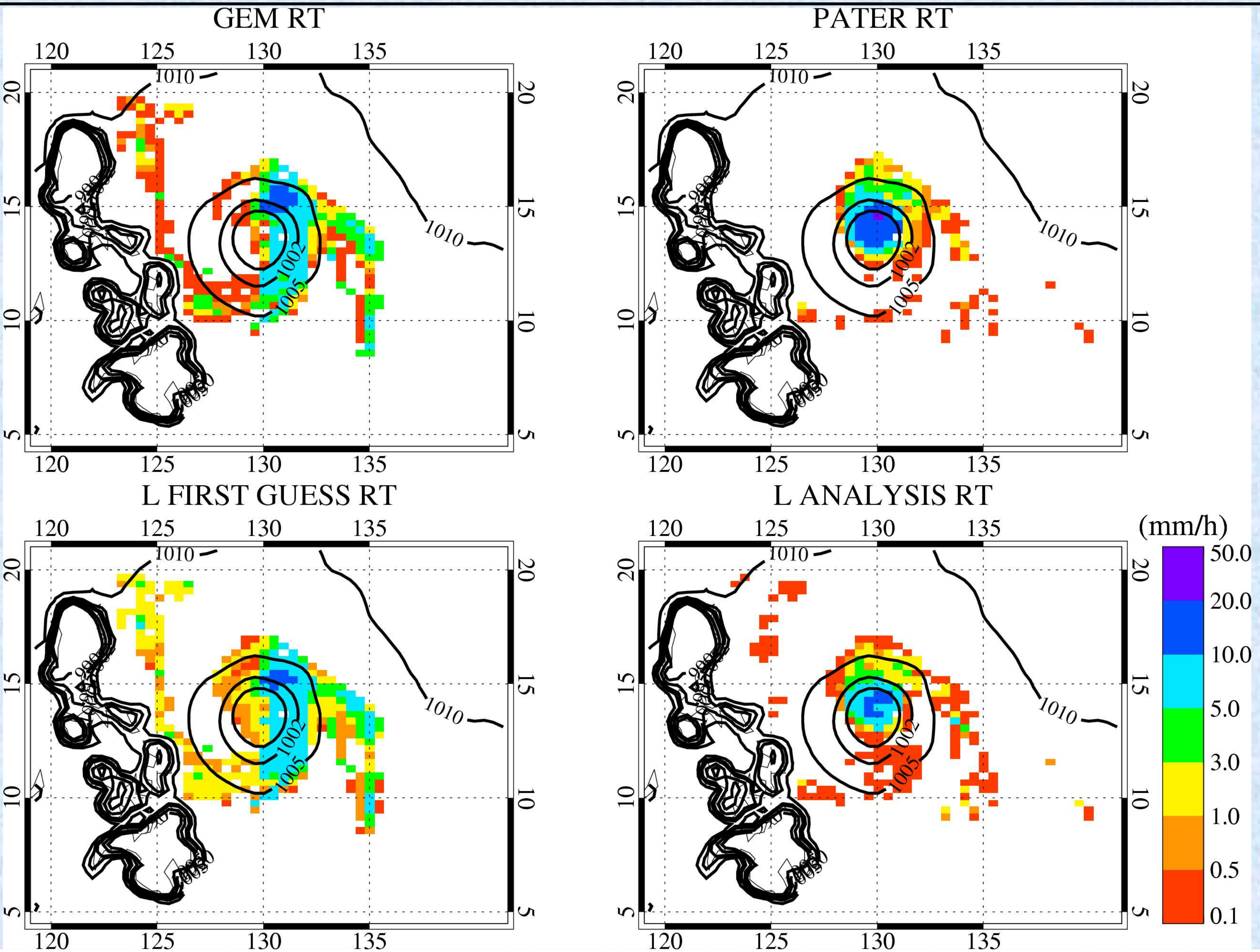
- **CLOUDST not RTTOVSCATT**
- **SAME with 1D-VAR SRR**



RC=CONVECTIVE SRR
RT=TOTAL SRR

TROPICAL CYCLONE ZOE
Valid at 2002 12 27 0000 UTC

SUPER-TYPHOON MITAG 2002 03 05 1200 UTC (TMI KFJT P=12h forecast): SRR



SUPER-TYPHOON MITAG 2002 03 05 1200 UTC (TMI KFJT P=12h forecast)
profiles ok= 99.2% . TMI time of overpass 1055 UTC.

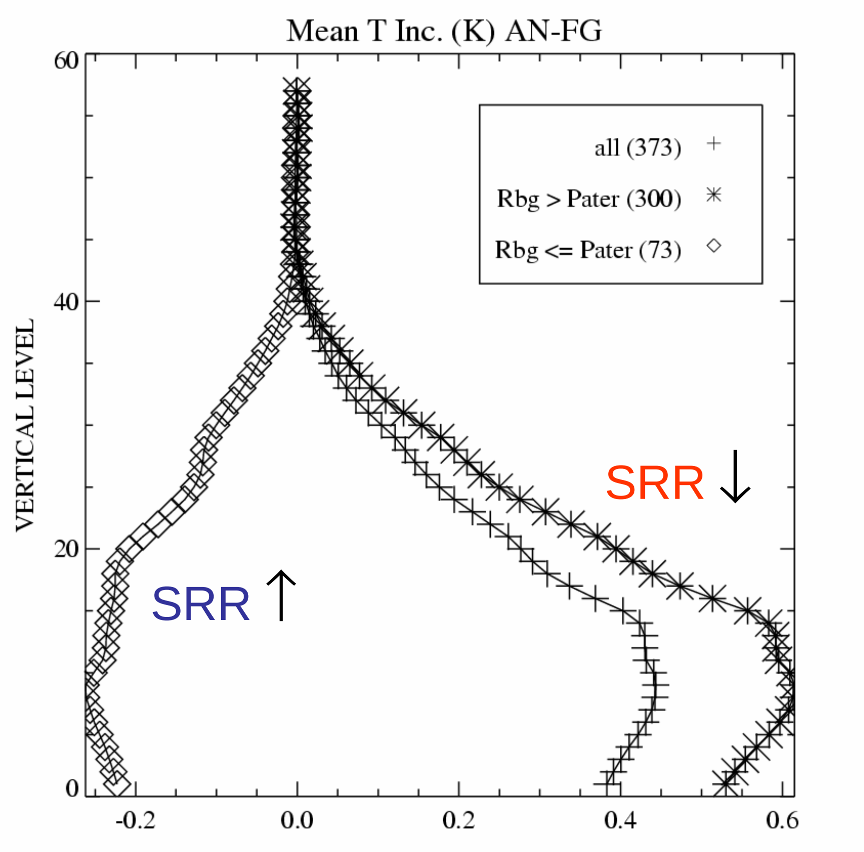
BRIGHTNESS TEMPERATURE (K)

Channel	O-P		O-A			Tb obs.
TMI	Bias	SD	Bias	SD	N	Error
11V GHz	-15.0411	18.4459	-3.44116	2.78661	379	3.0
11H GHz	-27.9502	33.6220	-6.65266	5.17876	379	6.0
19V GHz	-15.3135	19.3598	0.749076	2.40929	379	3.0
19H GHz	-31.4902	36.4494	-1.79683	4.47256	379	6.0
22V GHz	-8.07467	9.33276	0.114512	2.00437	379	3.0
37V GHz	-21.5061	15.2950	-2.03260	2.50424	181	3.0
37H GHz	-42.5099	31.7399	-2.17459	4.16556	181	6.0

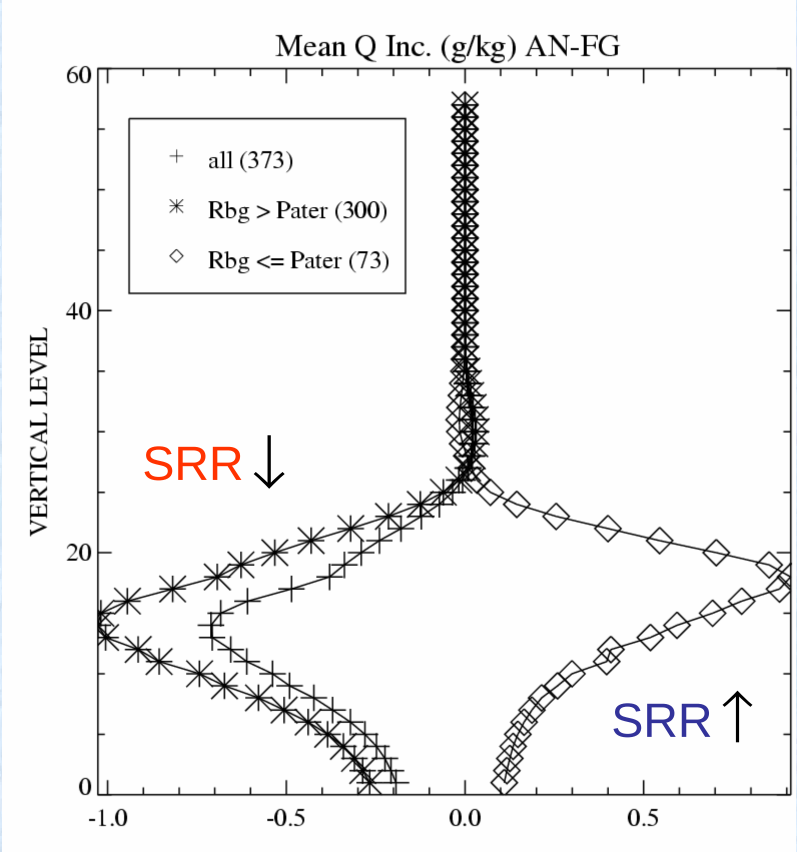
TMI Surface Rain Rate PATER CAL (mm/h)

O-P		O-A		
Bias	SD	Bias	SD	N
-1.51522	4.16225	0.537039	1.31324	373

Super-Typhoon Mitag Valid at 2002 03 05 1200 UTC: T and Q Inc. Assimilation of TMI Tb

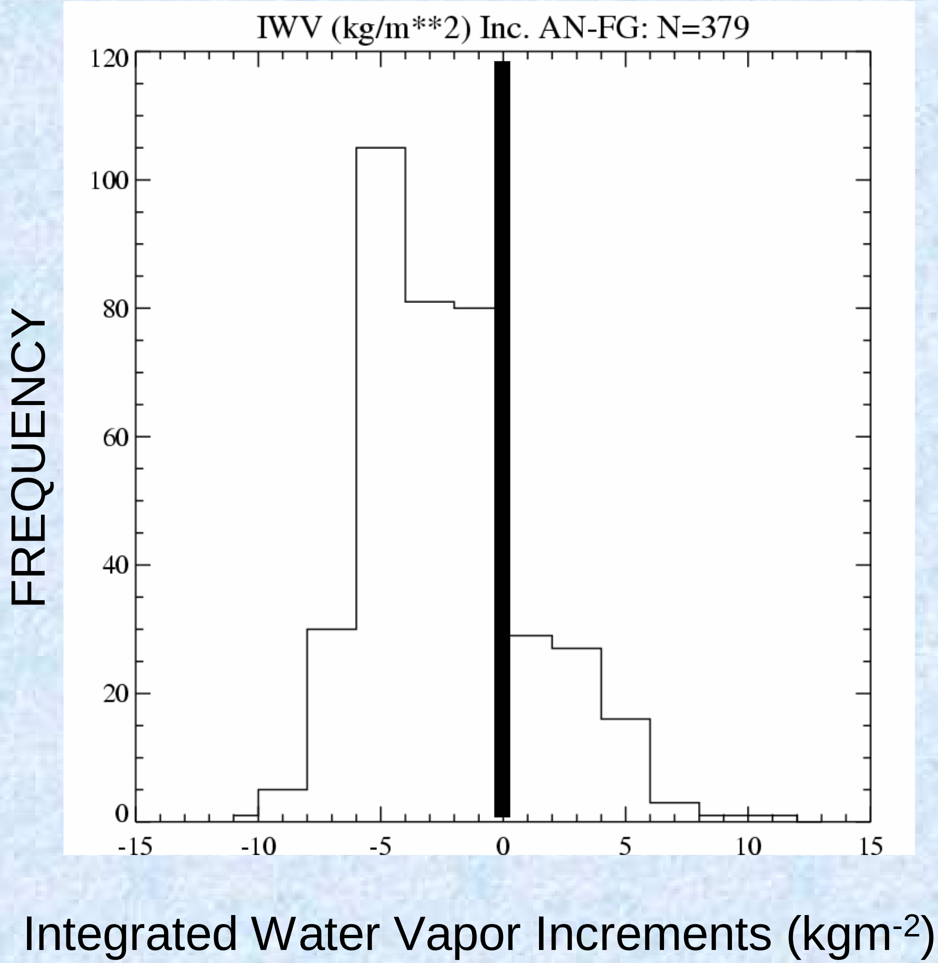


Temperature increments (K)

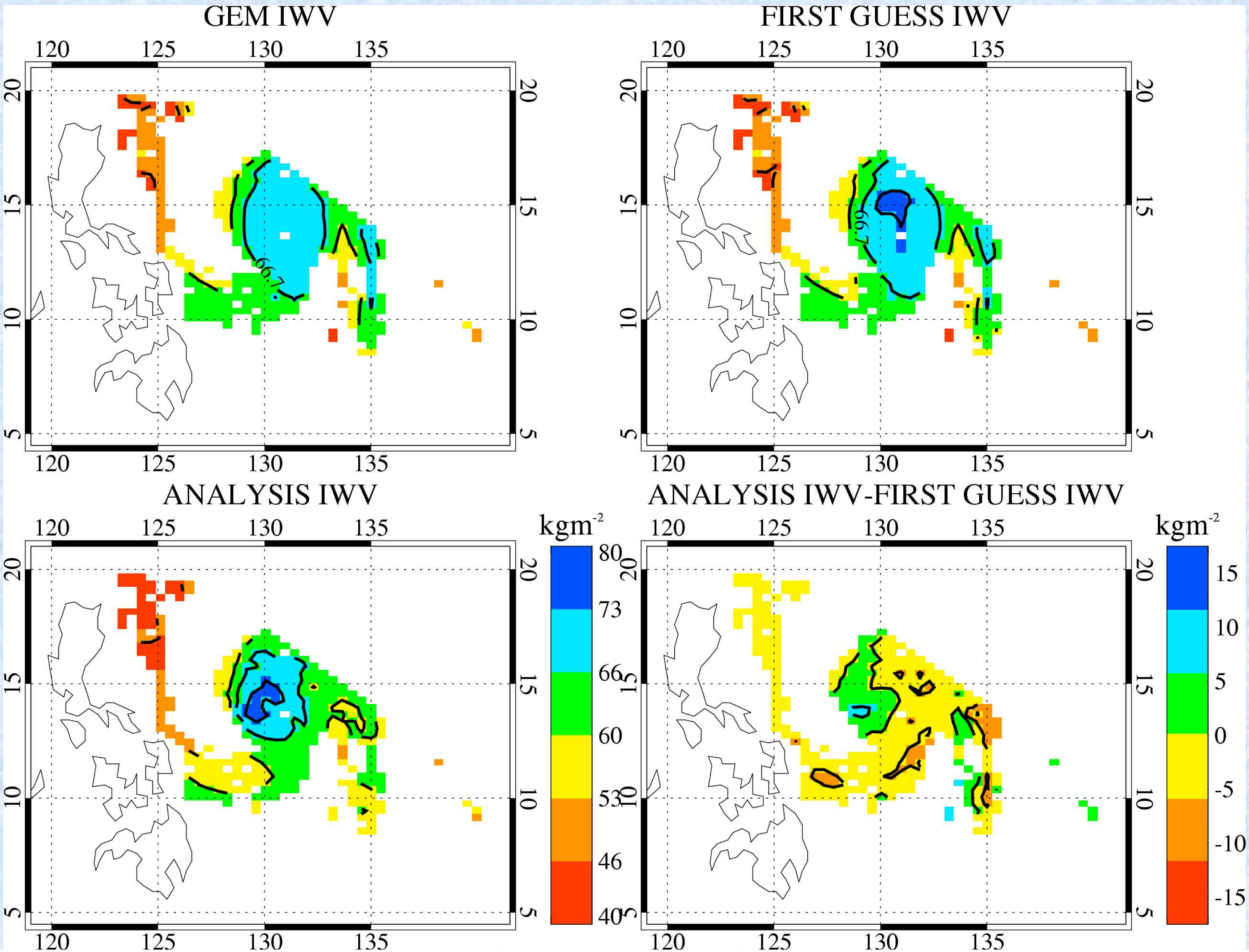


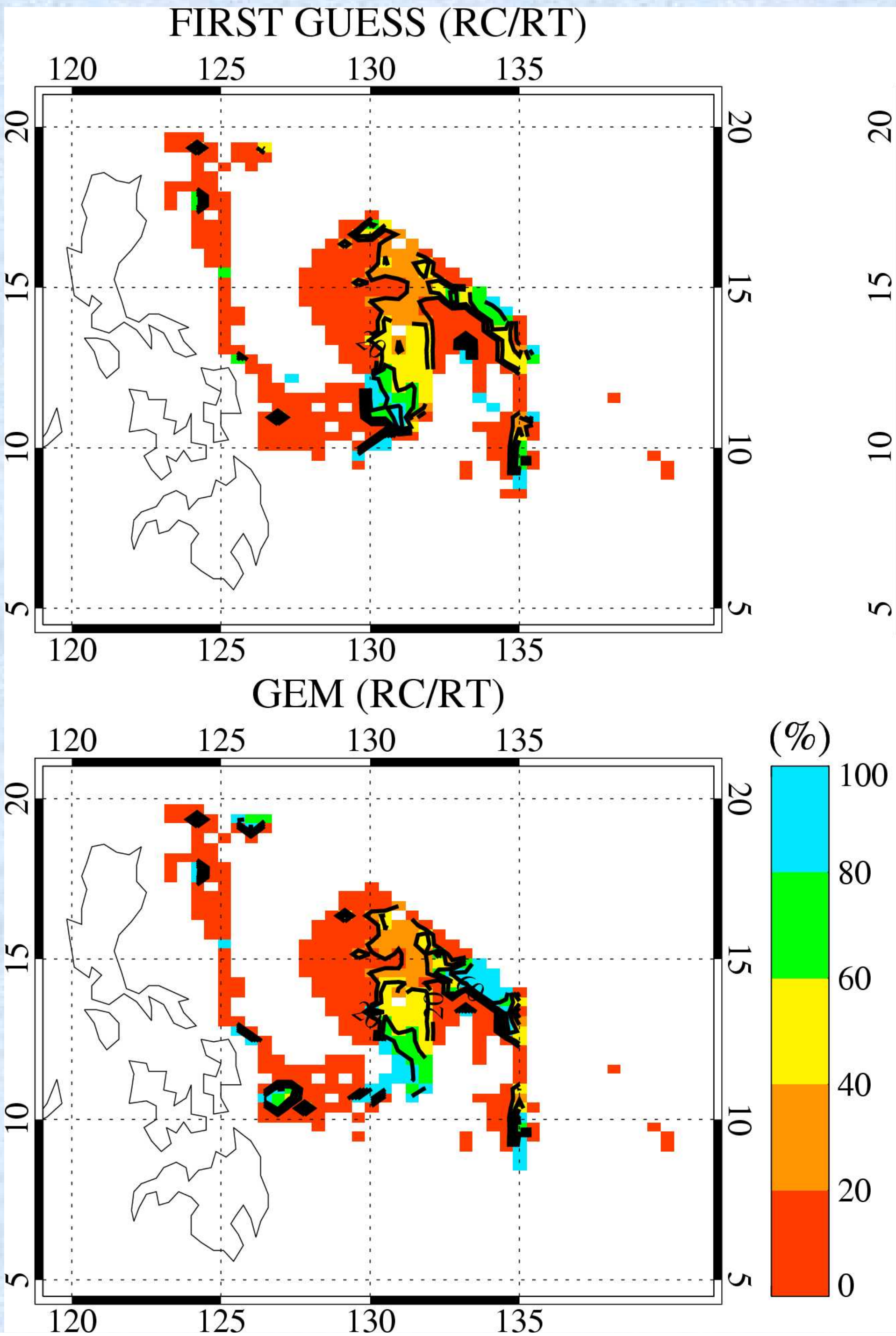
Specific Humidity increments (gkg^{-1})

Super-Typhoon Mitag Valid at 2002 03 05 1200 UTC: IWV Inc.
Assimilation of TMI Tb



SUPER-TYPHOON MITAG 2002 03 05 1200 UTC (TMI KFJT P=12h forecast): IWV





RC=CONVECTIVE SRR
RT=TOTAL SRR

Super-Typhoon Mitag
Valid at 2002 03 05 1200 UTC

CONCLUSIONS

- 1D-Var Tb developed (RTTOVSCATT –SSM/I or TMI) and functional
- Schemes of moist physics are Kain-Fritsch + CLOUDST (TJ 2003)
- Showed successful analyses results for 2 tropical cyclones: Zoe and Mitag - Analyses draws to the observations as expected
- Larger T increments (~ 0.4-0.6 K) than those obtained at ECMWF
  - due to CLOUDST not RTTOVSCATT

  1D-Var SRR analyses experiments show T increments of similar magnitude –not the case with ECMWF COND scheme (large-scale precipitation scheme –w/o clouds).
- Assimilating 1D-Var Tb retrieved IWV in a 4D-Var system at this stage therefore does not appear to be an option

FUTURE WORK

- Replace CLOUDST (TJ 2003) with CONSUN (sundqvist variant)
  so that the 1D-Var forward operator (moist physics processes)
  more accurately reproduces GEM modeled SRR
- Validation with TRMM radar rain flux product (14 GHz radar) possible
- Perform information content study (with simulated observations)
  Look at
  - Saturation problem of Tb w.r.t SRR
  - Sampling procedure for Tb in model grid box
- Direct assimilation of Tb in the GEM-LAM 3D-Var (Fillion et al.). Implement RTTOV8. September 2004