One-Dimensional Variational Assimilation of SSM/I Observations in Rainy Atmospheres at Environment Canada (EC)

Science & Technology Branch

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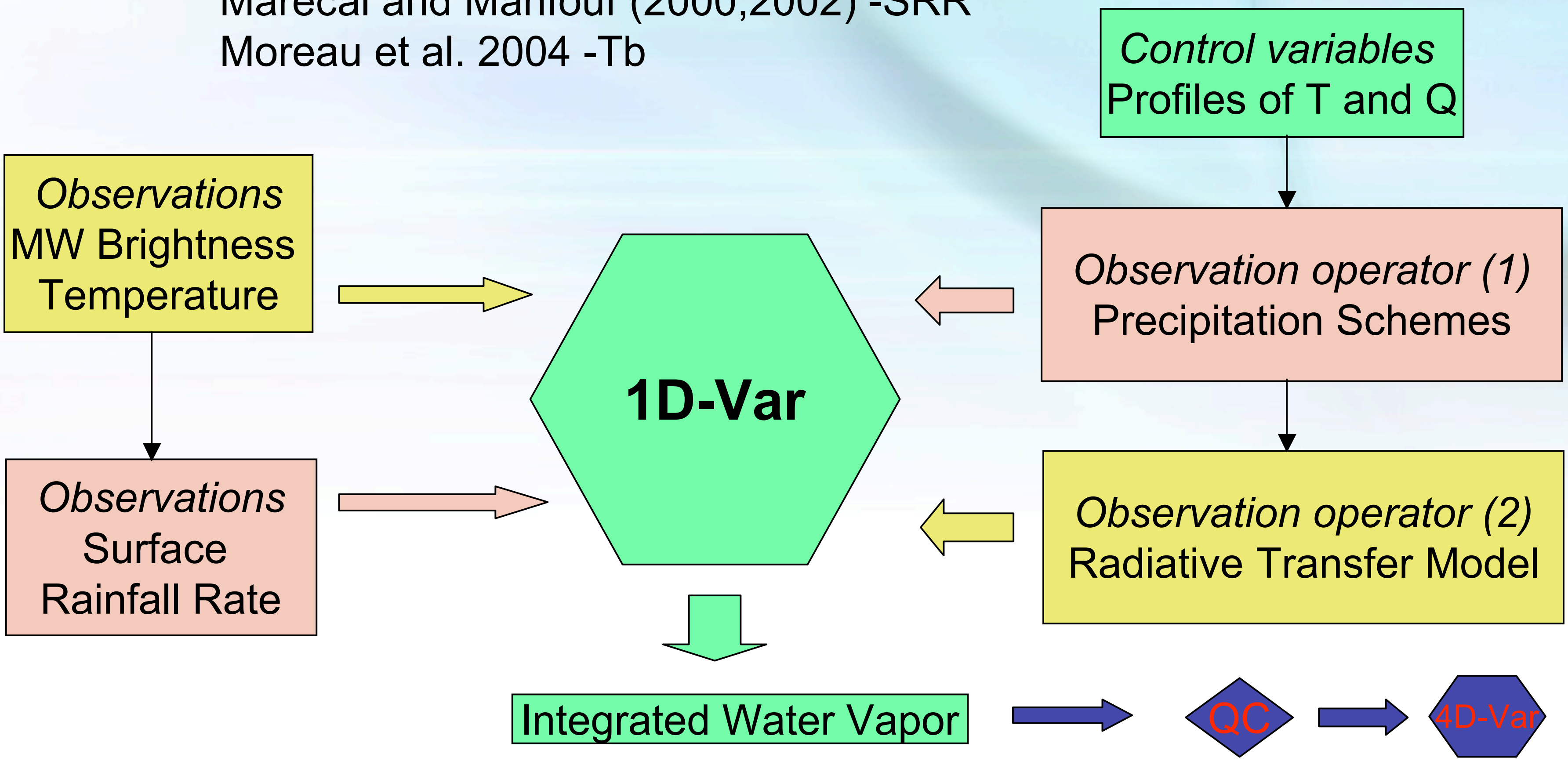
Motivation

- Development at EC of an assimilation system of satellite radiances in cloudy and rainy regions (over open oceans)
- Operational NWP centers
  - **JMA** : Mesoscale 4D-Var assimilation of radar precipitation
  - **NCEP** : Global 3D-Var assimilation SSM/I and TMI derived rainfall rates
  - **ECMWF** : Towards a global 4D-Var assimilation of SSM/I radiances in rainy areas
    - Two step method (1D-Var+4D-Var) operational since June 2005 (Bauer et al. 2006 a and b, QJRMS)

Proposed strategy

Marécal and Mahfouf (2000,2002) -SRR
Moreau et al. 2004 -Tb



Experimental set-up

- Control variable : T and ln(q) profiles (58 levels)
- Observations : SSM/I brightness temperatures (Tb) or derived surface rain rates (SRR) (Bauer et al. 2002)
- Observation operator :
  - **Moist physical processes :** same as in EC global forecast model (GEM) –*jacobians obtained by finite difference*
  - **Radiative transfer model :** RTTOV with scattering effects (Bauer and Moreau, 2002) –*jacobians obtained by adjoint method*
- Background error statistics : “NMC” method (lagged forecasts) as in EC operational 4D-Var (incremental)
- Two case studies (40S-40N):

  Tropical Cyclone Zoe (F15) & Typhoon Chaba (F14)

Background Term

- **Forecast Model**:
  - Global Environmental Multi-Scale (**GEM**) MESOGLOBAL -research
  - Model Resolution: 0.45° longitude x 0.3° latitude grid
  - 58 vertical levels, model lid at 10 hPa, time-step = 15 minutes

- **Moist physical schemes**:
  - Shallow Convection: KuoTrans -> only cloud liquid water
  - Non-convective (or stratiform): CONSUN (Sundqvist variant)
  - Deep Convection: Kain-Fritsch (CAPE) ->**highly non-linear**

- **12-h precipitation spin-up:**

  → 1D-Var background field = 12-h forecast

Number of SSM/I Tb channels assimilated

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

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

(Petty 1994)

- 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

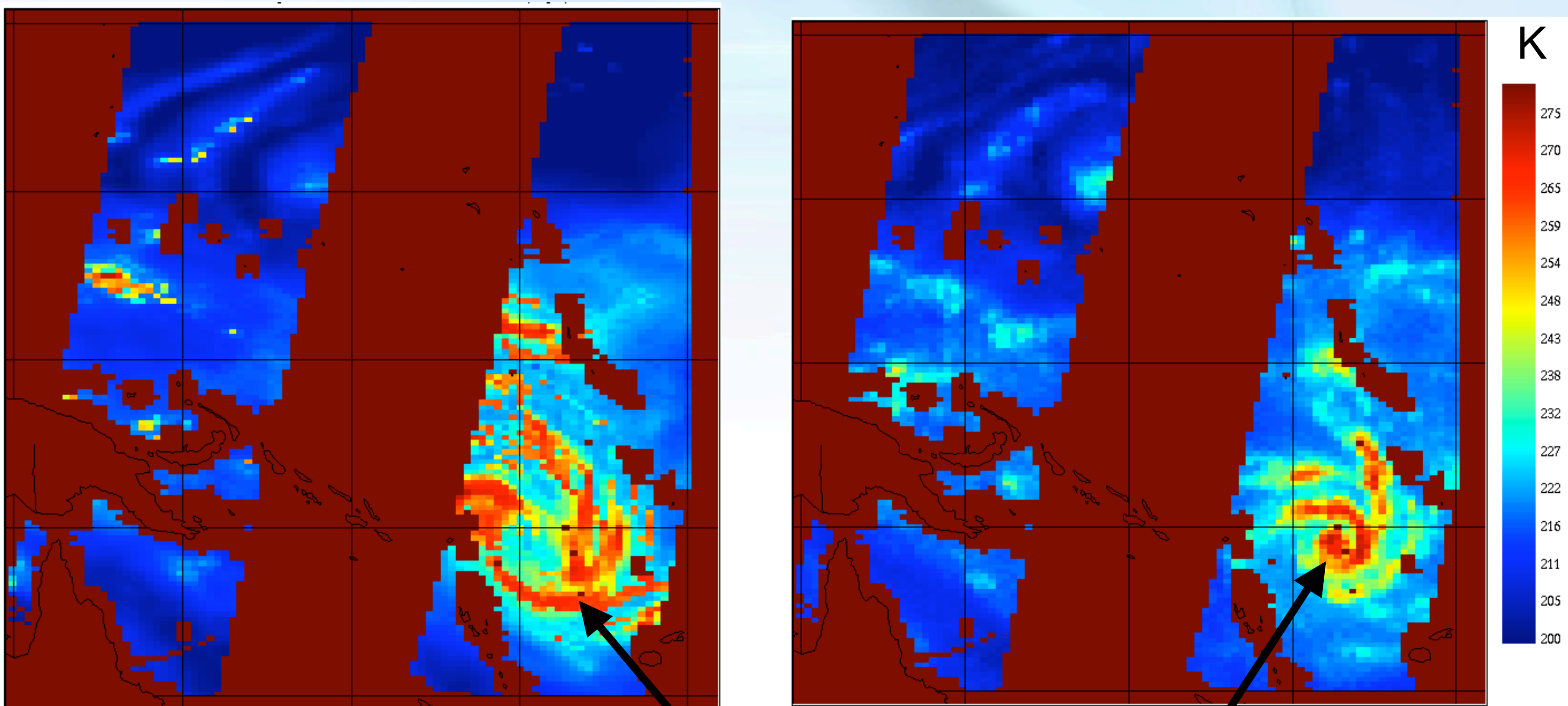
If P > 0.15 (τ=Transmittance > 0.4) **then** Use (19V,H,22V, 37 V,H)

Else Use 19V,H, 22V ONLY

Brightness Temperature (K) at 19 GHz V 2002 12 27 000 UTC

GEM Mesoglobal 12h Forecast

SSM/I F15 Observations

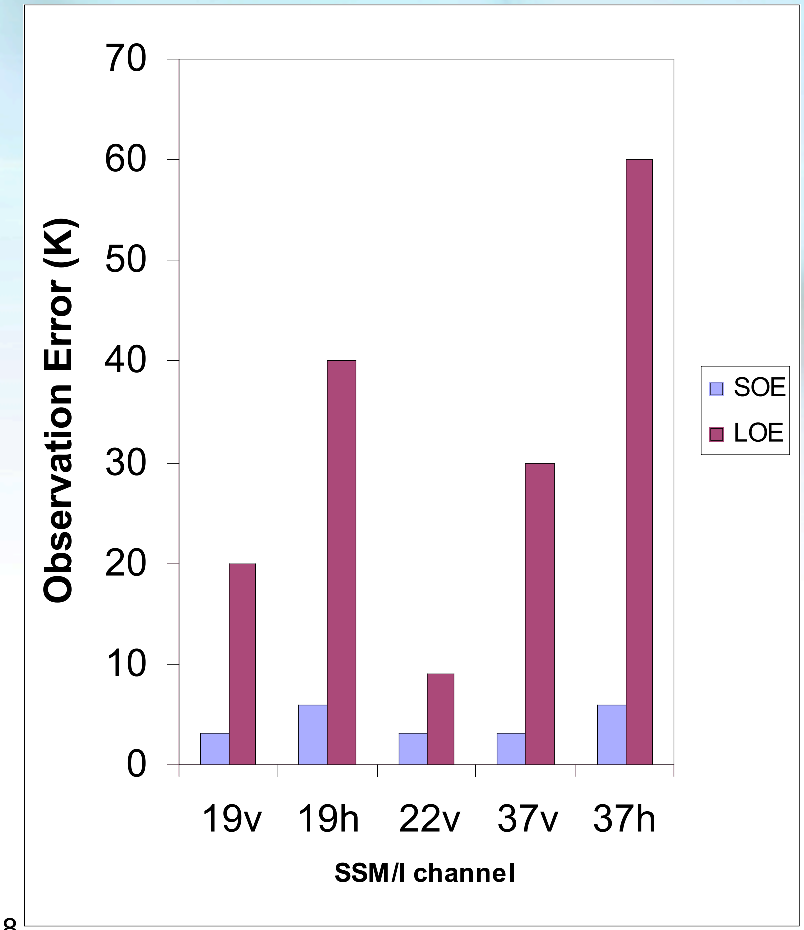


Tropical Cyclone Zoe

Experiments

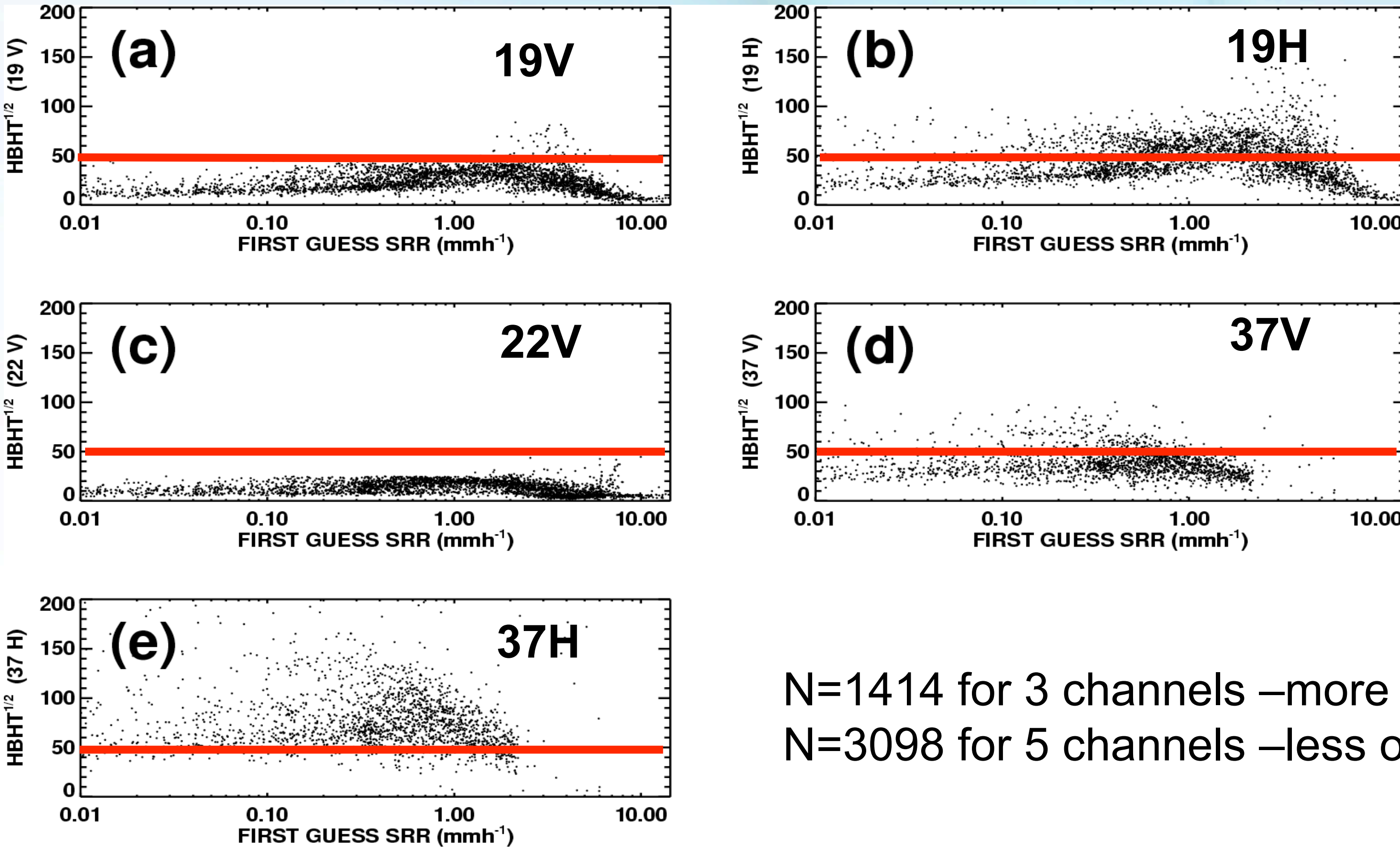
- **1D-Var Tb** – **Small Observation Errors (SOE)**
  - (O+F) = 3 K for V channels & 6 K for H channels (as in Moreau et al. 2004)
- **1D-Var Tb** – **Large Observation Errors (LOE)**
  - (O+F) = HBH^T
- **1D-Var SRR** (Surface Rainfall Rate) –Observation error provided by retrieval algorithm

1D-Var Tb Observation Error (K)



Zoe Case: 0000 UTC 27 Dec 2002

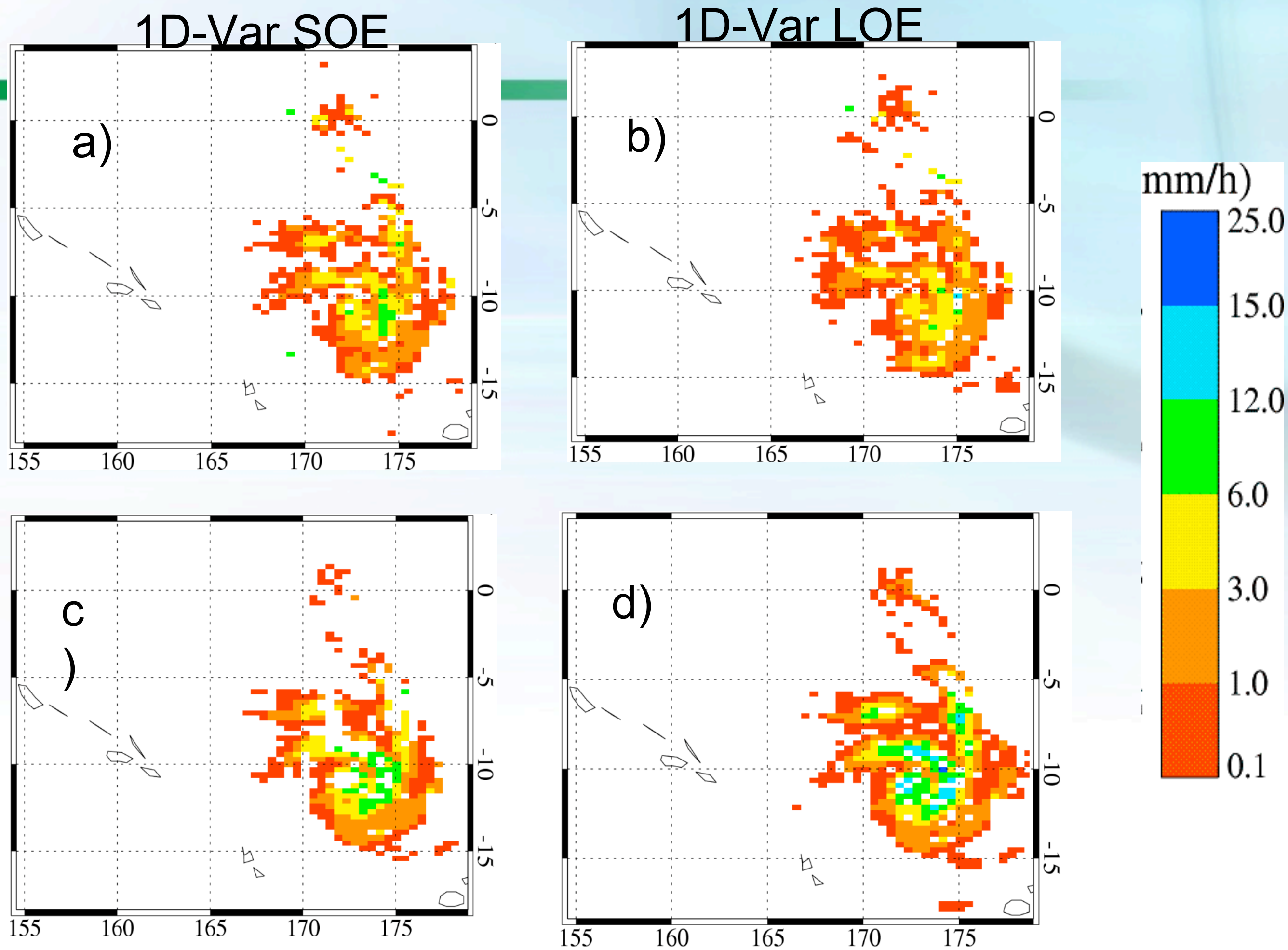
$(HBH^T)^{1/2}$ in Kelvin



N=1414 for 3 channels –more opaque

N=3098 for 5 channels –less opaque

TC Zoe: Analyzed Surface Rain Rate (mm/h)

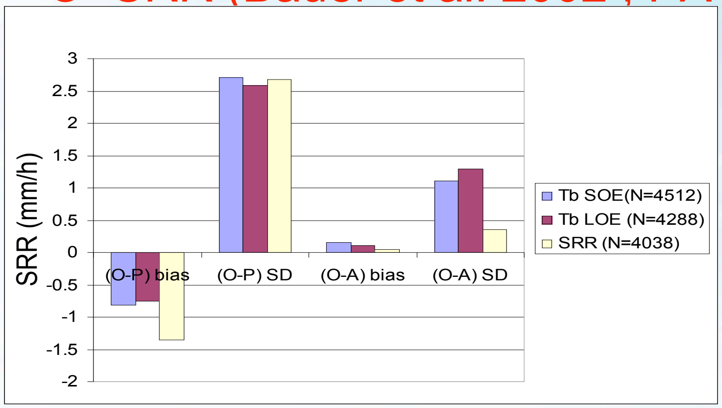


1D-Var SRR

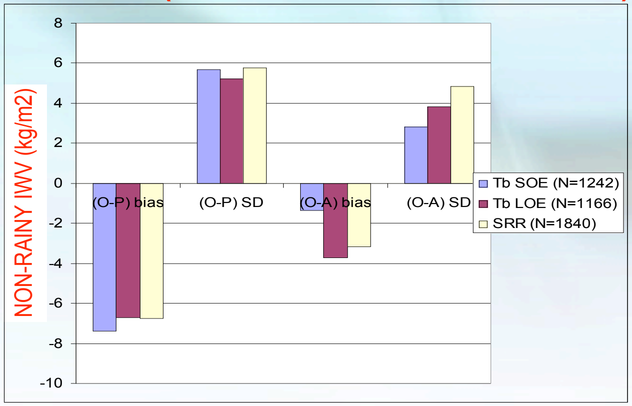
PATER observations SSM/I F15

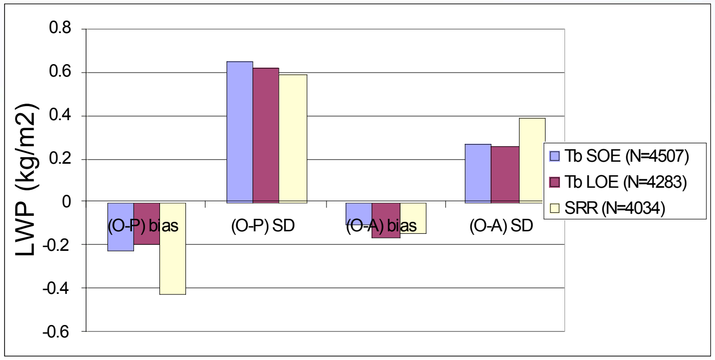
Analyzed fields vs SSM/I retrievals based on regression equations

O=SRR (Bauer et al. 2002 , PATER)



O=IWV (Alishouse et al. 1990)

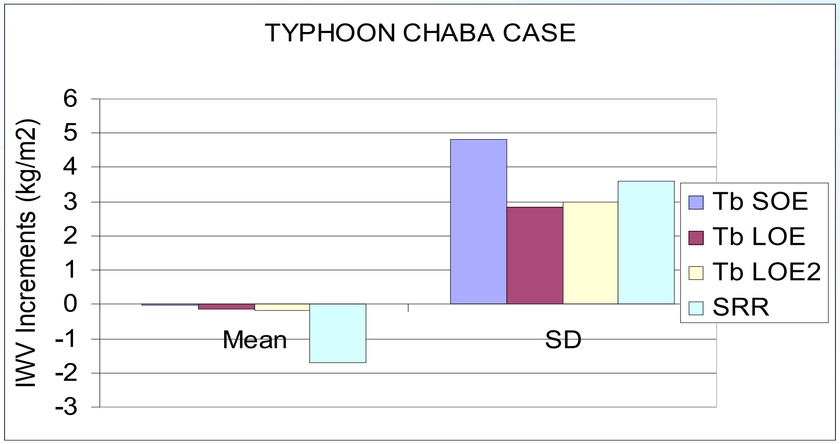


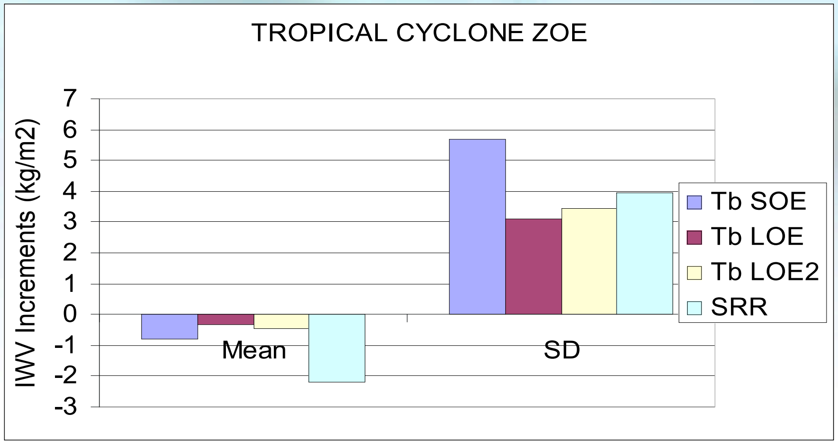


O=LWP (Weng & Grody, 1994)

Integrated Wapor Vapor (IWV) increments (kgm^{-2})

Increment = (Analysis-Background)

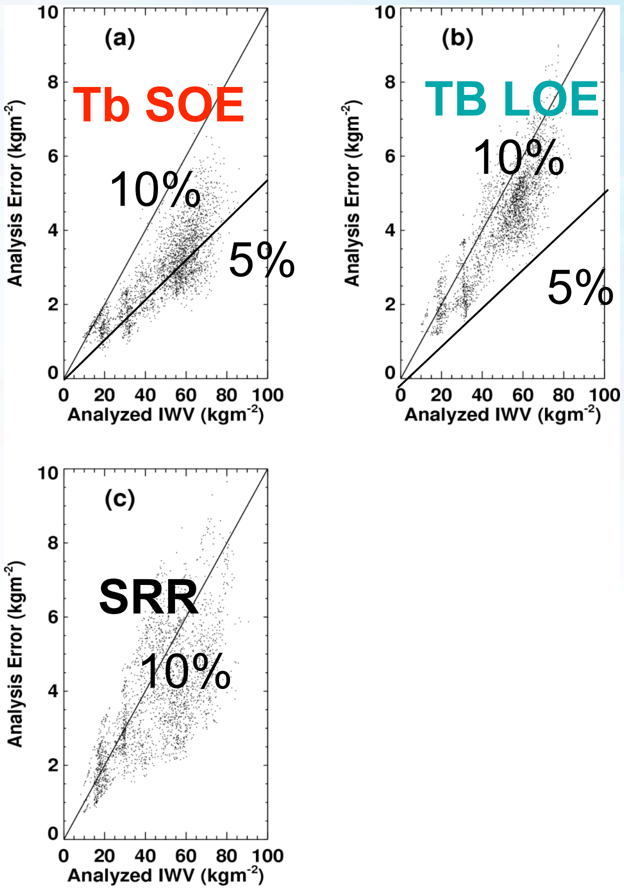




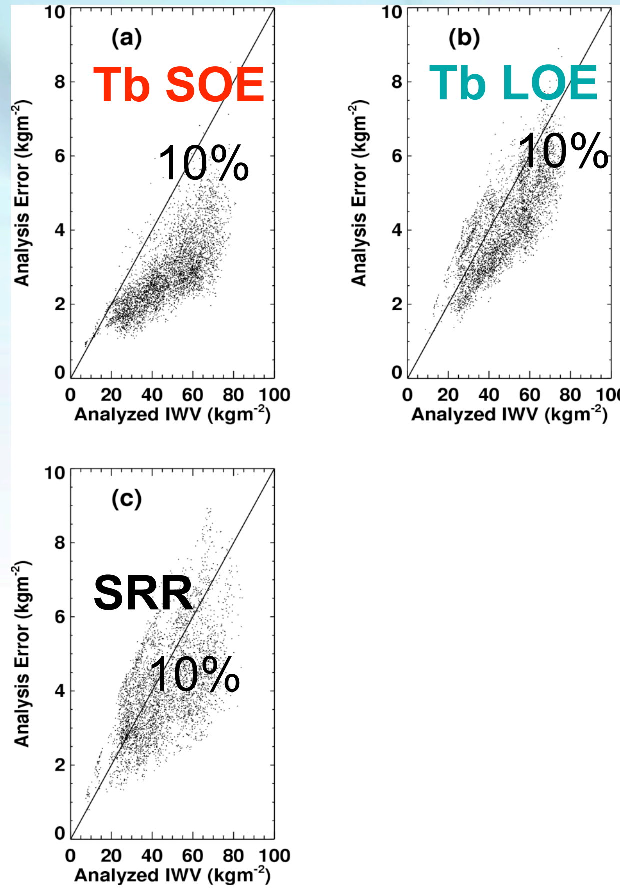
Analyzed IWV error estimate

$A = [\, B^{-1} + H^T R^{-1} H \,]^{-1}$, Rodgers (2000)

Chaba

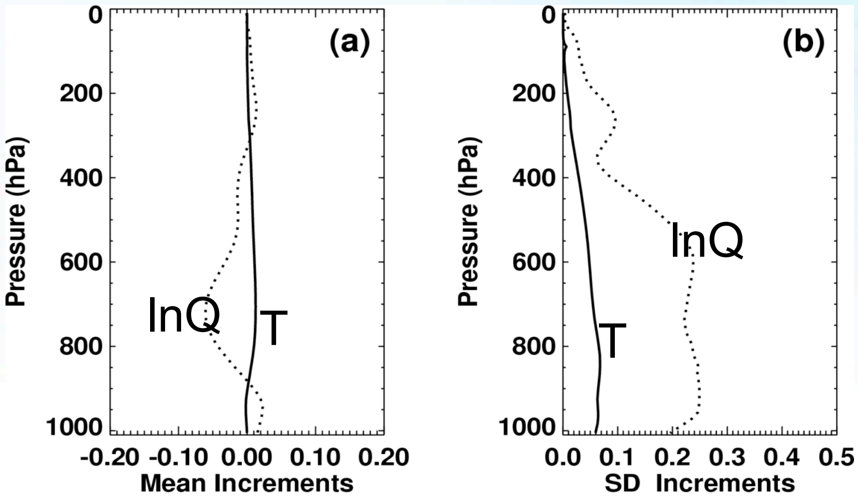


Zoe

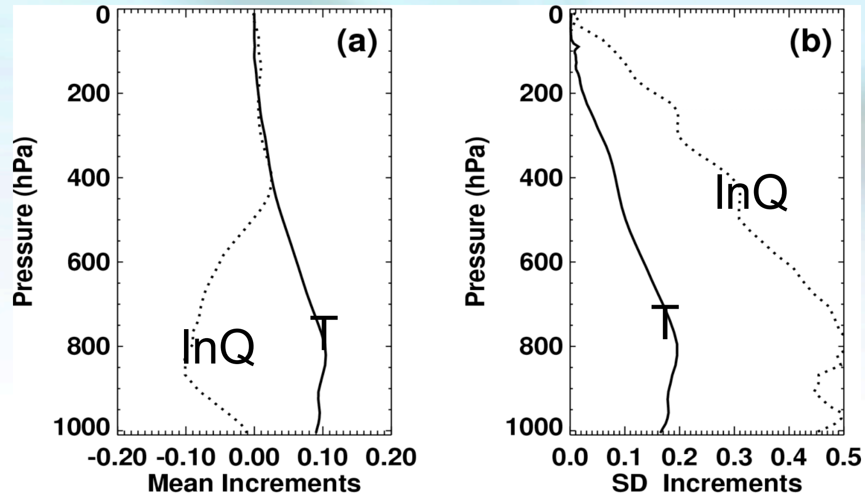


Size of temperature and humidity increments (normalized by background errors) for Zoe

(Analysis-Background)



1D-Var Tb LOE



1D-Var Tb SOE

Conclusions

- 1D-Var Tb and SRR developed (RTTOVSCATT-SSM/I or TMI) with GEM moist physical schemes
- Successful analyses for Tropical Cyclone Zoe and Typhoon Chaba (> 95% convergence).
- 1D-Var Tb SOE experiment: weight given to observations is too large and leads to large water vapor increments.
- Largest contribution of observation error comes from the moist physics (in particular deep convection scheme) and hence affects the 1D-Var behavior
  - Explicit scheme favored (larger sensitivity to humidity)
- Assimilation of Tb, rather than SRR, should be favored in the variational assimilation context due to the direct dependence of Tb on cloud liquid water path and integrated water vapor.
- Correlation of observation error between different channels is important for five channel set (less opaque atmosphere implies more parameters to define).
- Applying moist physical schemes ("linearized") from other NWP centers (developed specifically for DA) not trivial because schemes need to be tuned for model of center. Evaluate the impact of assimilating 1D-Var IWV in the EC global 4D-Var
  - Need to improve the computing efficiency of the 1D-Var
  - Tb bias correction
- Paper accepted to appear in Monthly Weather Review

Thank you!