Assimilation of cloudy radiances from satellite infrared imagers and sounders

Kozo Okamoto (JMA/MRI),
Tony McNally (ECMWF), Bill Bell (UKMO)

Outline
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3. Preliminary study in more generally cloud cases
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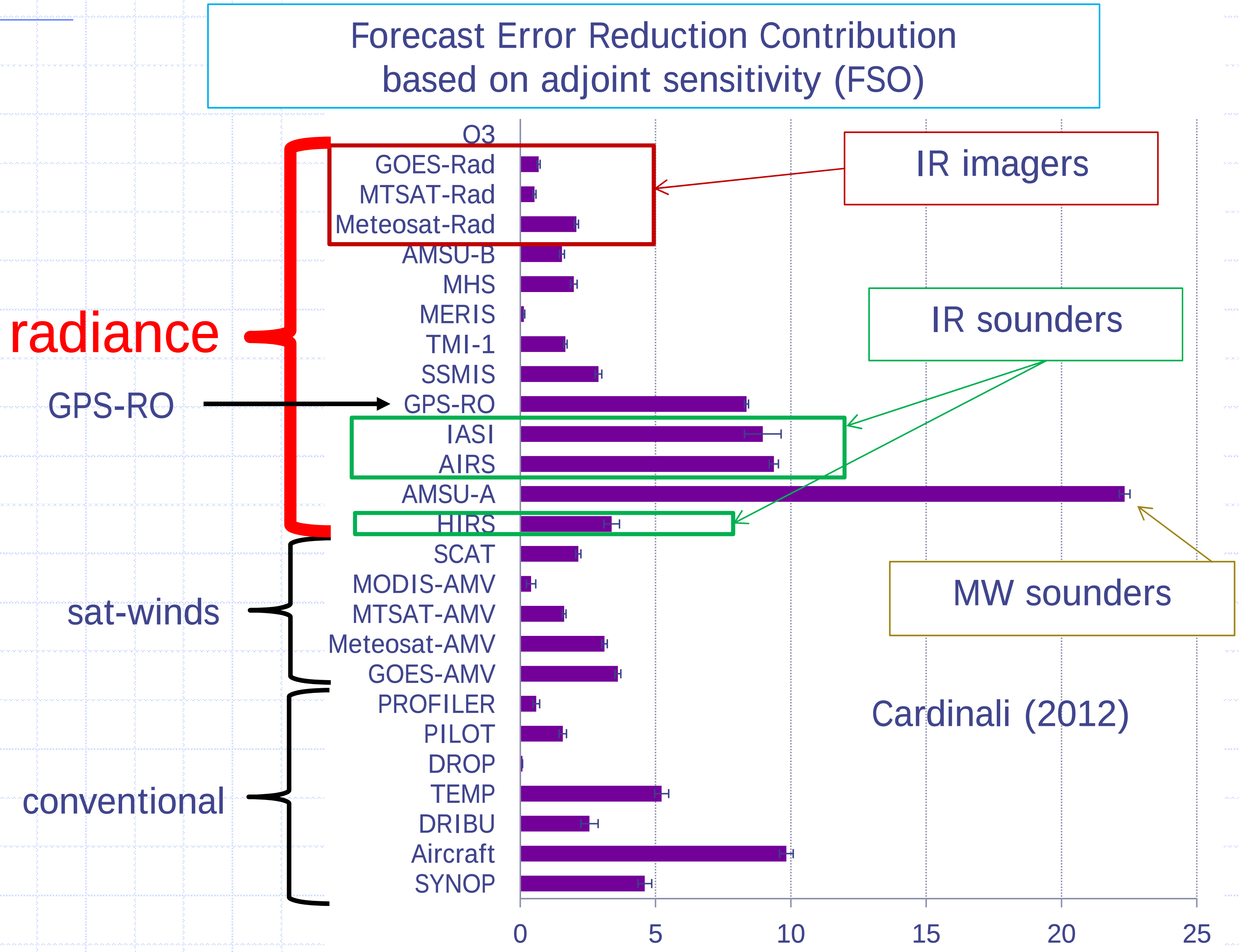
Background

- Satellite radiance data from sounders/imagers have been playing significant roles on NWP data assimilation
- But use of cloud/precipitation-affected radiances is still limited especially for infrared (IR) spectral region.
  - Cloudy IR radiances are assimilated at some NWP centers. But this is only for thick, homogeneous, single-layer (simple) cloud case

Impact comparison of satellite data



Target of this study

- 1. Assimilate simple cloud IR radiances of imagers on geostationary (geo-) satellites (Okamoto 2012)
  - Previous studies are mainly for sounders on polar-orbiting satellites
  - Fewer channels but higher temporal resolution

- 2. Investigate the viability to assimilate more generally cloudy IR radiances (Okamoto et al. 2012)

Simple cloud case

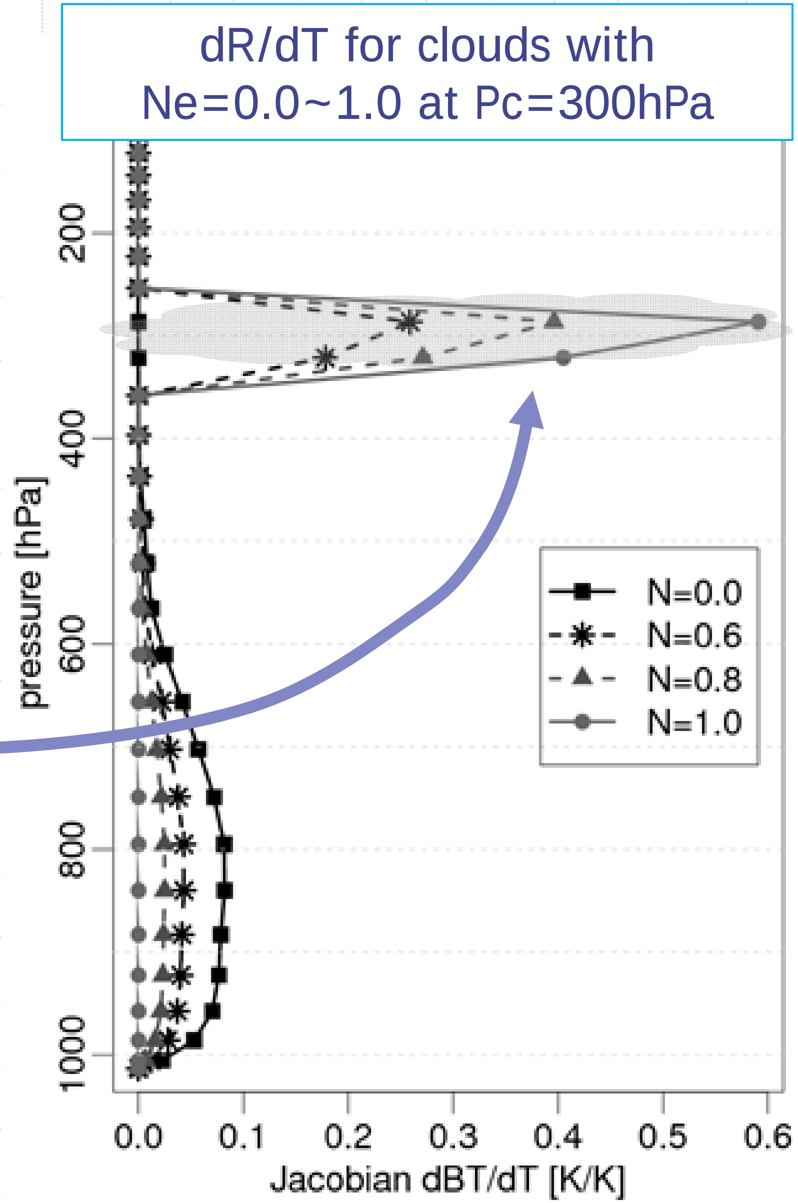
- Radiative Transfer Model (RTM) for simple cloud
  - $R_i = R_i^c (1 - N_e) + R_i^o N_e$
    - R_i^c : clear-sky radiance of channel i
    - R_i^o : completely overcast radiance from a blackbody cloud at top pressure P_c
    - N_e : effective cloud fraction = (geometric fraction N)*(cloud emissivity e)
  - **Condition 1**: This simple RTM is valid only for thick, homogeneous, single-layer cloud
- N_e & P_c are calculated by minimizing $J = \Sigma_i^{Nch}(R_i^m - R_i)^2$
    - R_i^m : observed radiance at channel i
  - **Condition 2**: N_e is the same at all channels in J (e consistency)

- Carefully select data satisfying these two conditions
- Handle representative scale difference btw obs & DA system
- ➔ OSRs with N_e>0.8, clear-sky ratio<5% and 160<P_c<650hPa
    - Overcast Super-ob Radiances (30km in radius)

Assimilation of MTSAT-1R OSRs

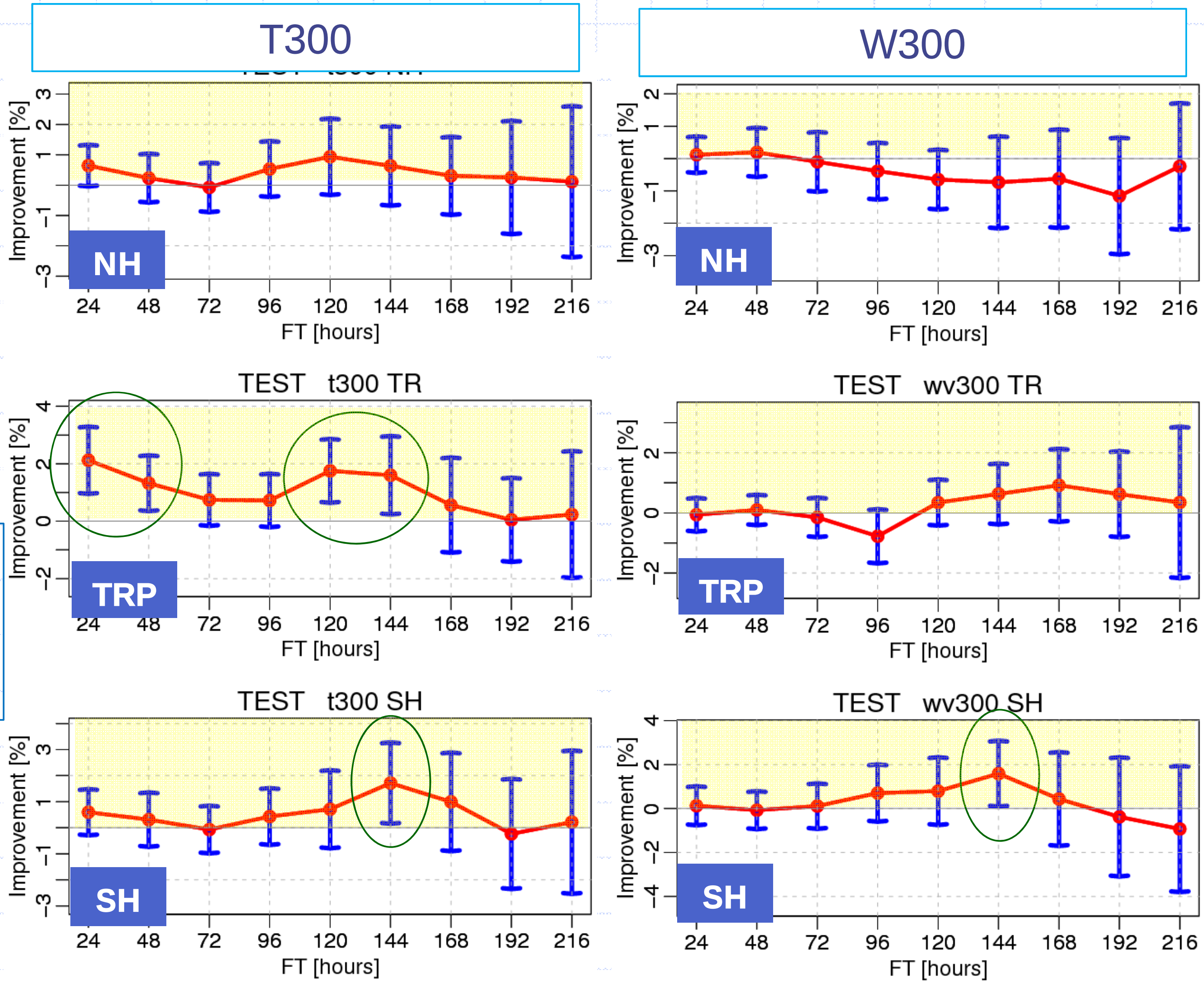
- Assimilate OSRs at IR1 (11um) channel of MTSAT-1R in JMA global 4D-Var
  - N_e & P_c are given from background and fixed in minimization

- Advantages of OSRs from geo-sat
  - 1. High availability in cloudy regions where even MW sounders are rejected
  - 2. High vertical resolution of temperature at the cloud top
  - 3. High temporal resolution
    - But IR1 assimilation has not yet shown clear result
      - Probably IR3 (humidity-ch) assimilation will work better (Lupu & McNally, 2012)



Forecast improvement by OSR assimilation

- Neutral or slightly positive impact



Improvement Rate :
・normalized forecast RMSE difference
・positive → improvement

Summary of OSR assimilation (simple cloud cases)

- Easy implementation
  - Planning an implementation in the operational system after adding more channels and geo-satellites

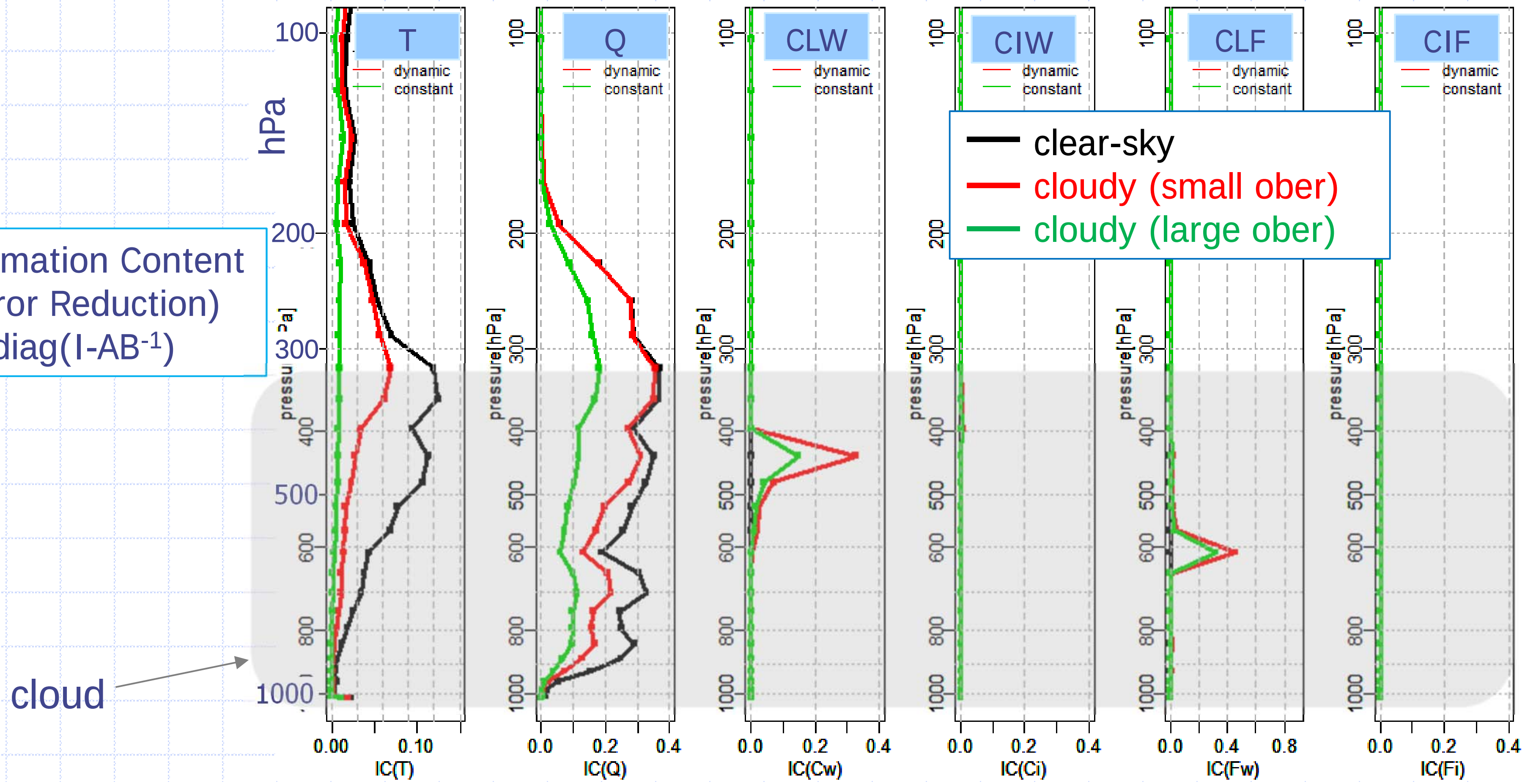
- However, cloudy radiance data are still limited in use
  - Applicable to only homogeneous, thick, single-layer cloud (simple) case

- → Investigate the viability to assimilate more generally cloudy IR radiances
  - Use more general RTM and cloud variables
  - As the first step, (hyperspectral) sounders are target of assimilation

Information content of more generally cloudy radiances

- Estimate analysis error based on optimal linear theory $A=(I-KH)B$
  - analysis variables: T,Q,liquid/ice-cloud content/fraction
- T/Q information can be obtained inside and below clouds for thin clouds
- Cloud information (content & fraction) can be also obtained

Information Content (Error Reduction) $\mathrm{diag}(I-AB^{-1})$

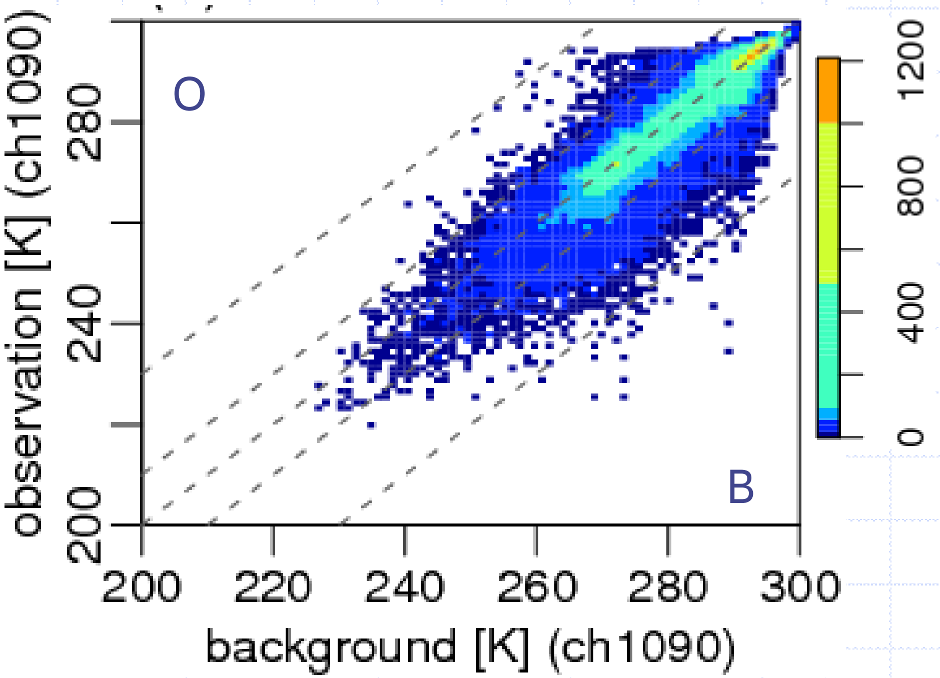


Evaluation of more generally cloudy simulation

- How accurately do NWP+RT models simulate cloudy IR radiances?
  - Comparison with hyperspectral IR sounder (IASI) measurement
  - NWP model : ECMWF operational model as of June 2012
  - RT model : RTTOV10.2 with cloud scattering effect (Matricaldi 2005)
  - 85% (69%) of all data over sea shows |O-B|<10K (5K)

B vs O
(window ch)

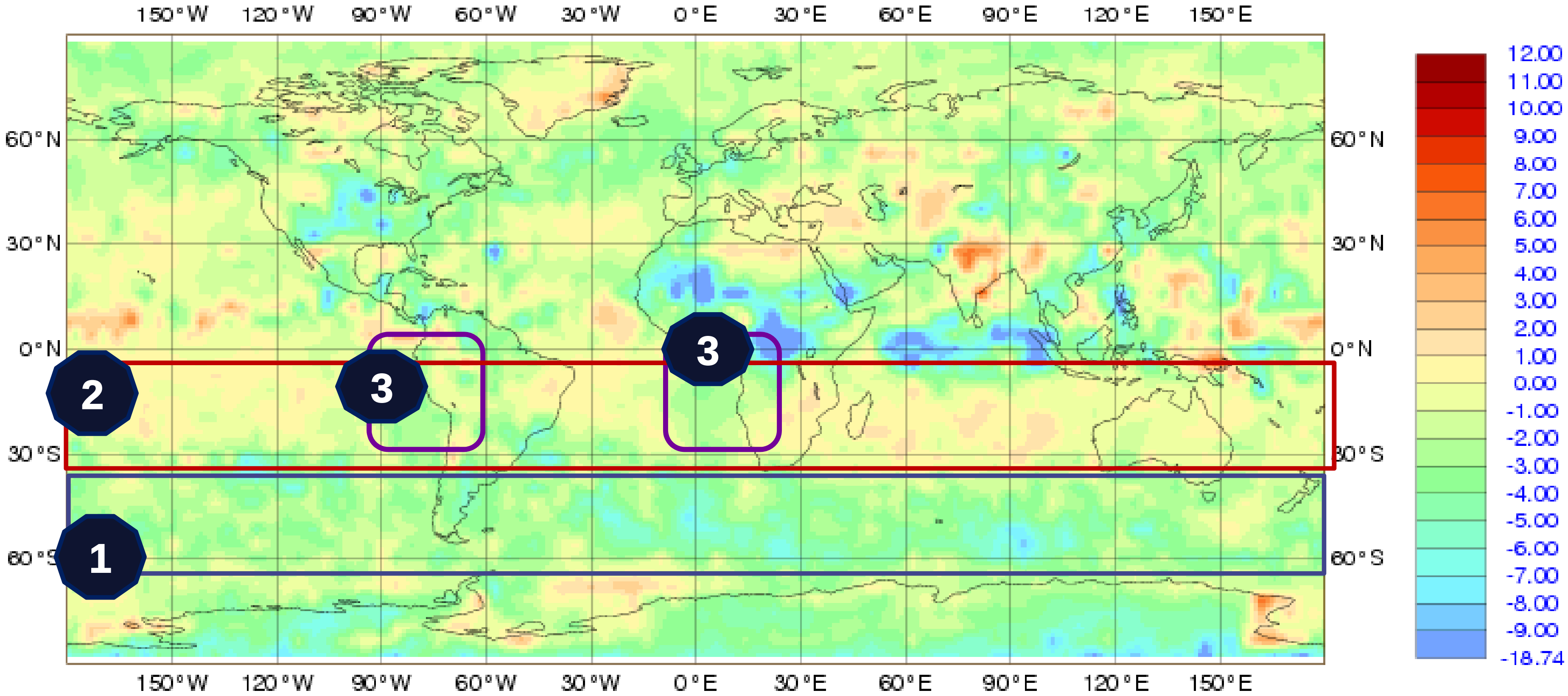
all data over sea from 1 to 13 Aug. 2012



O : observed brightness temperature (BT)
B : background (simulated) BT

O-B monthly average (June 2012)

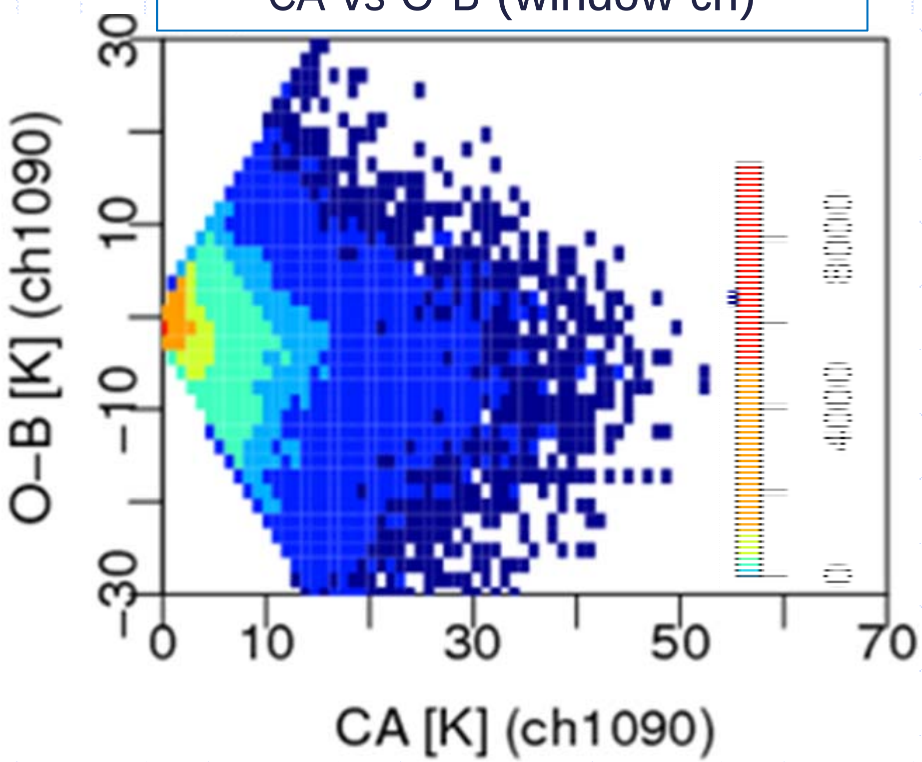
- Model clouds are
  - 1) Underestimated in 30-60S ← higher B ← negative O-B
  - 2) Overestimated in subtropical region ← lower B ← positive O-B
  - 3) Underestimated for stratocumulus off the west coast
- Consistent with O-B for all-sky MW radiances



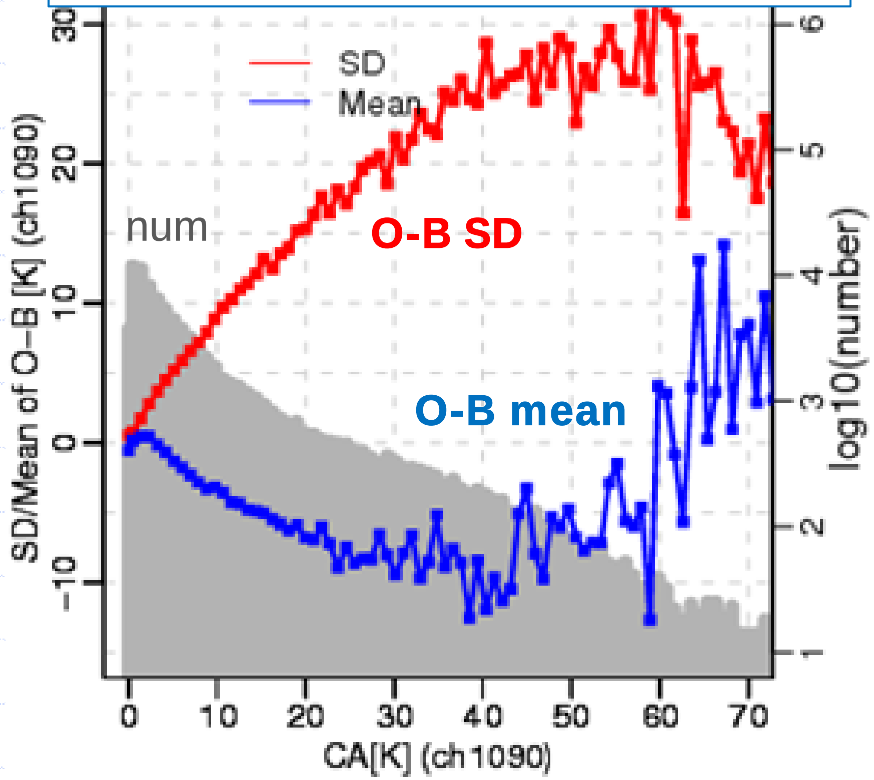
Cloud effect on O-B

- Examine cloud effect on O-B
  - Develop a new parameter representing cloud effect : CA
    - CA = 0.5*(|CB|+|CO|), CB=B-Bclr, CO=O-Bclr, Bclr=clear-sky simulation
  - As CA increases, O-B SD monotonically increases. After saturation (overcast condition) O-B SD decreases

CA vs O-B (window ch)

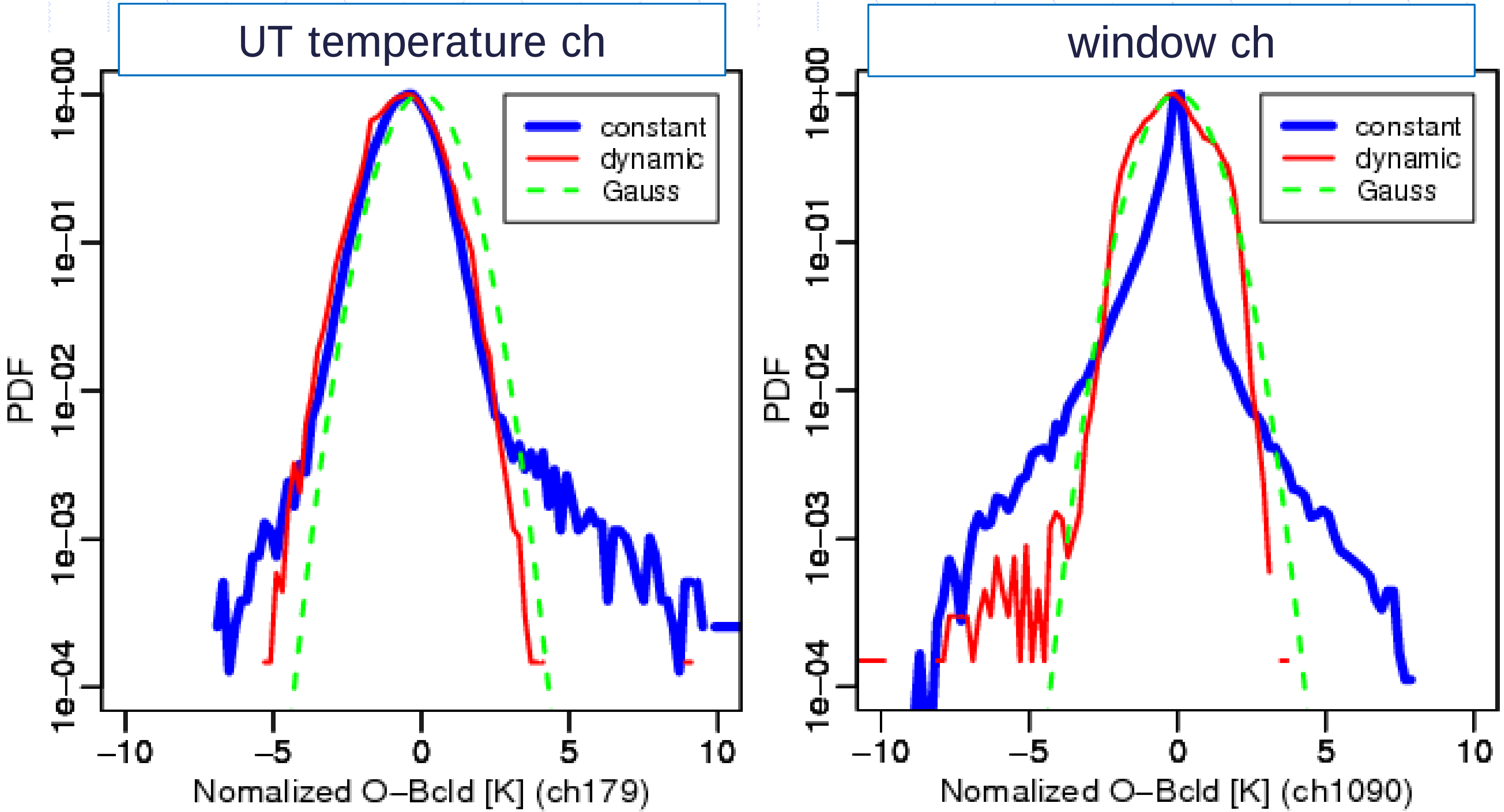


CA vs O-B SD & O-B mean



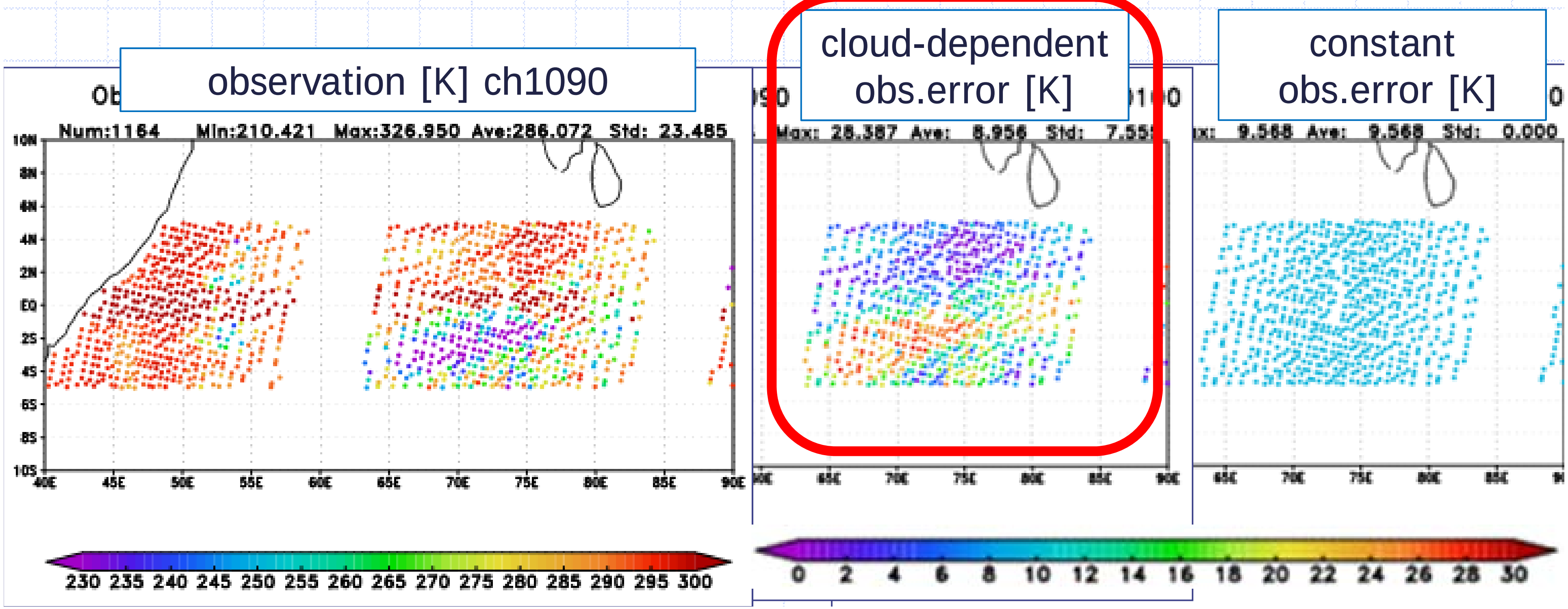
Gaussianity of normalized O-B PDF

- Normalized O-B (O-B/SD) PDF shows
  - Gaussian form for ch not strongly affected by clouds
  - Too peaked and long tailed form if cloud-dependency of SD is ignored
  - Gaussian form if cloud-dependent SD is used



Application of predicting cloud-dependent O-B SD

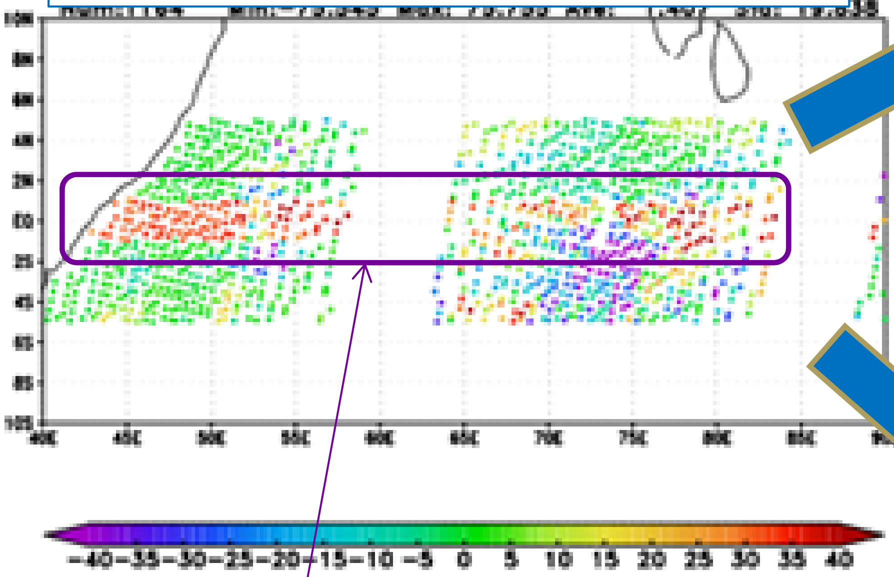
- 1. Cloud-dependent observation error assignment
  - if O-B SD is close to observation error (Geer & Bauer 2011)
- 2. Cloud-dependent QC
  - Threshold-based QC : reject data when |O-B|> a*SD
    - Cloud-dependent SD reasonably relax the threshold for cloudy obs
    - → More cloud-affected data reasonably pass the QC



Example : cloud-dependent QC

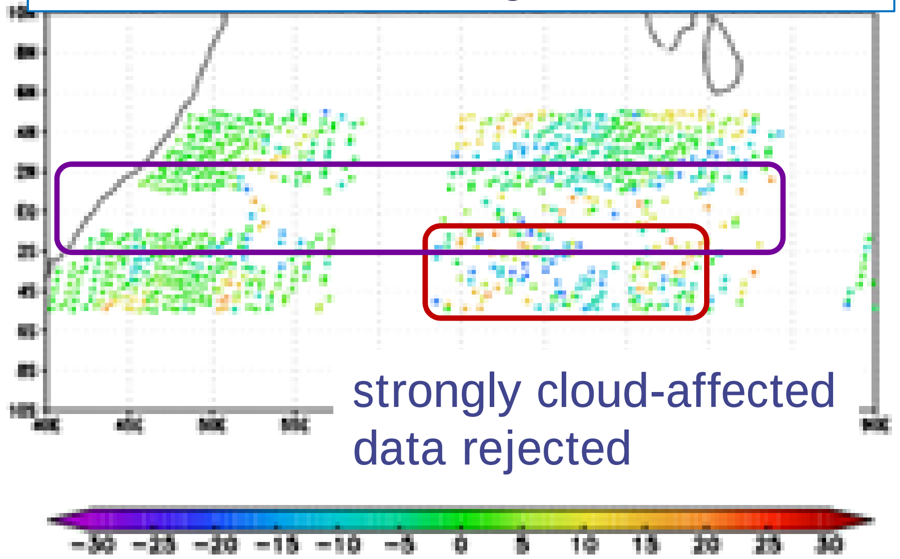
- reject data when |O-B|>2*SD

O-B before QC



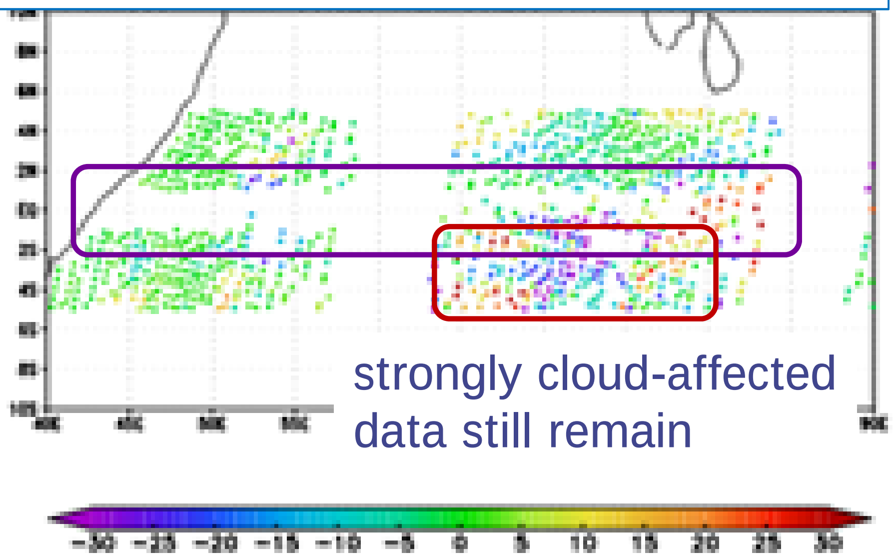
artificial gross-error
added to data in 1N-1S

O-B after QC using constant SD



strongly cloud-affected
data rejected

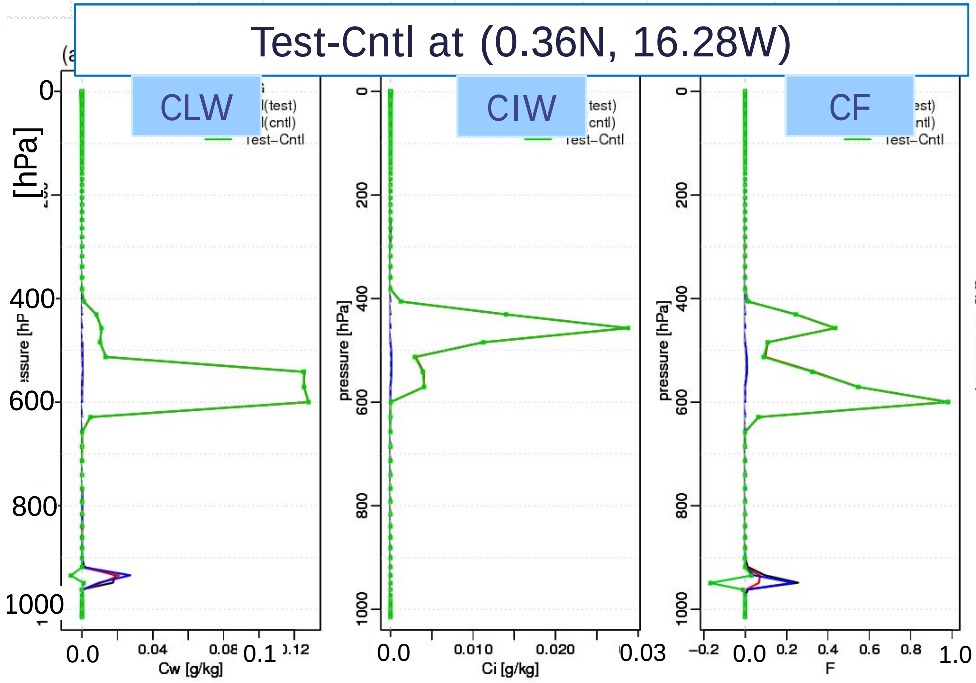
O-B after QC using cloud-dependent SD

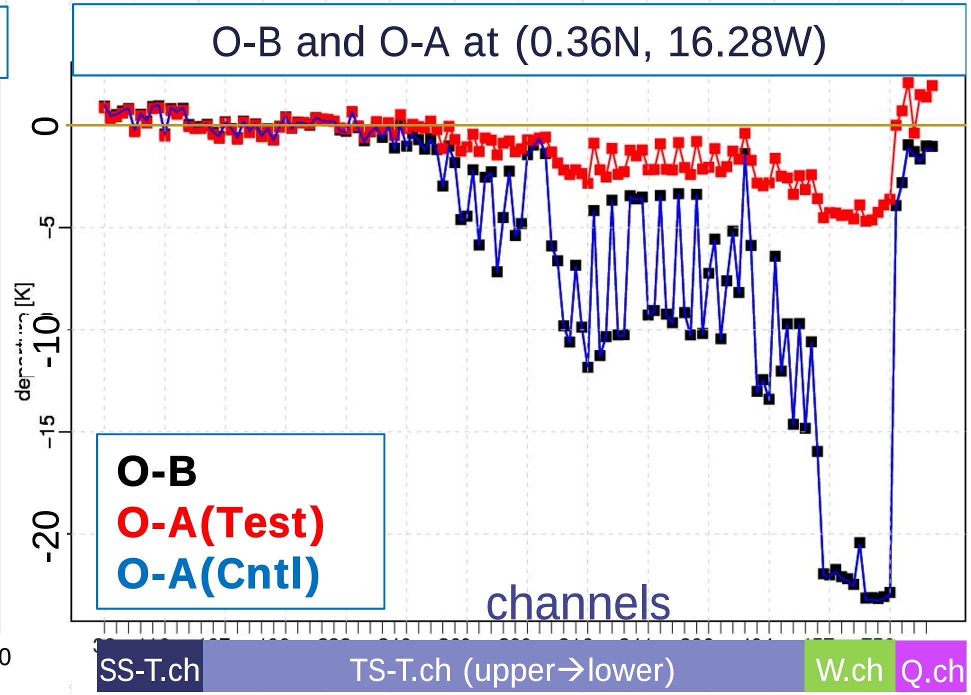


strongly cloud-affected
data still remain

Preliminary results of single ob assimilation

- IASI cloudy radiances at single point are assimilated in ECMWF operational DA system
  - Cntl: No other satellite data, Test: Cntl + IASI cloudy rad
- Clouds are not analysis variables but adjusted with simplified cloud & convective schemes in 4D-Var
  - cloud liquid water (CLW), cloud ice water (CIW), cloud fraction (CF)

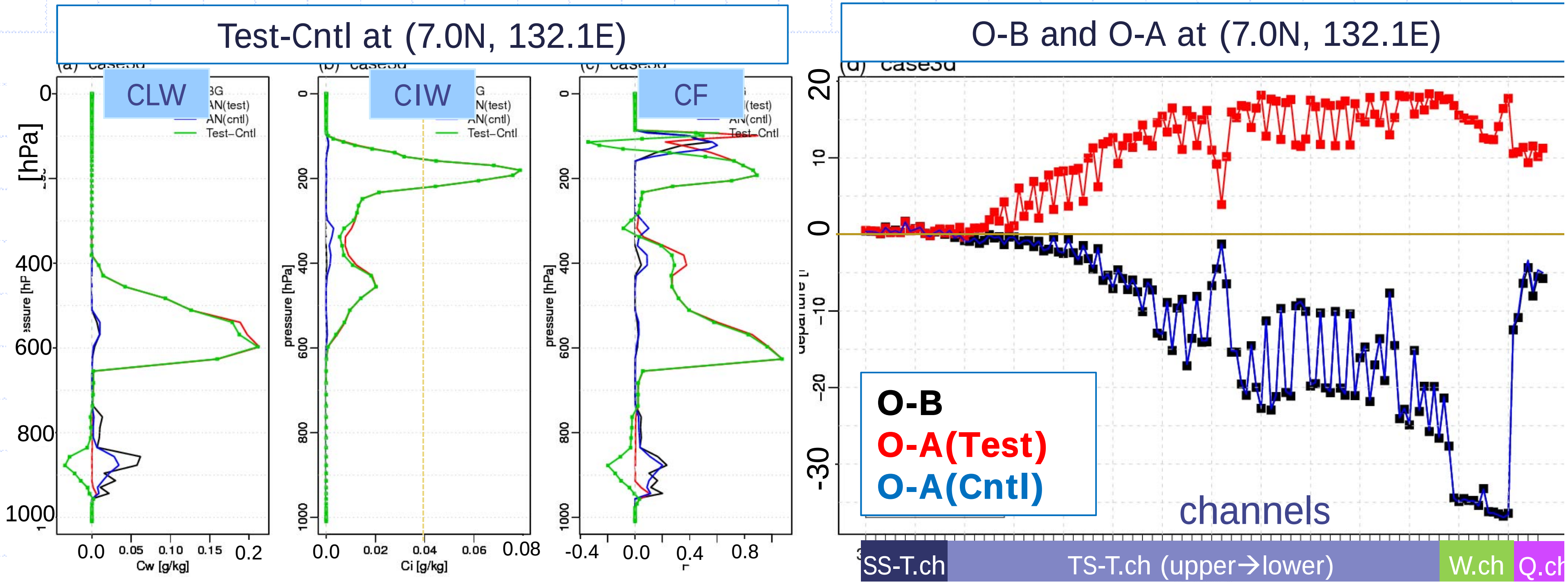




Preliminary results of single ob assimilation

- Overall, DA system properly increases/decreases clouds according to O-B
- However, it does not work well for CF~1 (“regularization”), bad initial state and complex cloud structure

clouds are excessively increased in this case!



Summary (1/2)

- To assimilate cloud-affected IR radiances, two approaches are being developed

- 1. Simple cloud approach : thick homogeneous single-layer clouds
  - Strict QC is necessary → very few available data
  - Slightly positive impact
  - Plans : Operational implementation after adding humidity channels and more geo-satellites

Summary (2/2)

- 2. More generally cloud approach
  - Develop a new cloud effect parameter and predict observation-minus-background (O-B) SD
    - Apply for cloud-dependent QC and observation error estimation
  - Optimum linear estimation analysis and single-observation assimilation experiments show promising results
  - Plans: investigate appropriate cloud control variables, treat strong non-linearity, improve cloud effect in RTM, develop bias correction and flow-dependent QC,,,
  - Plans : assimilate more cloud/precipitation-related data such as space-borne radar and lidar in flexible DA system

Thank you for your attention

Acknowledgement

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