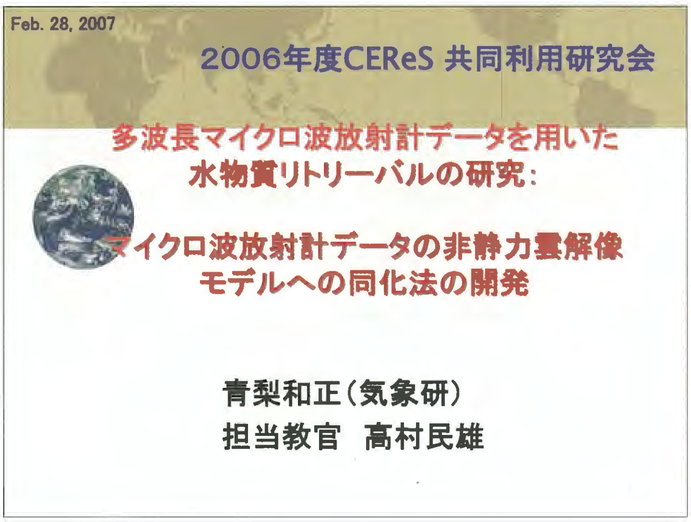
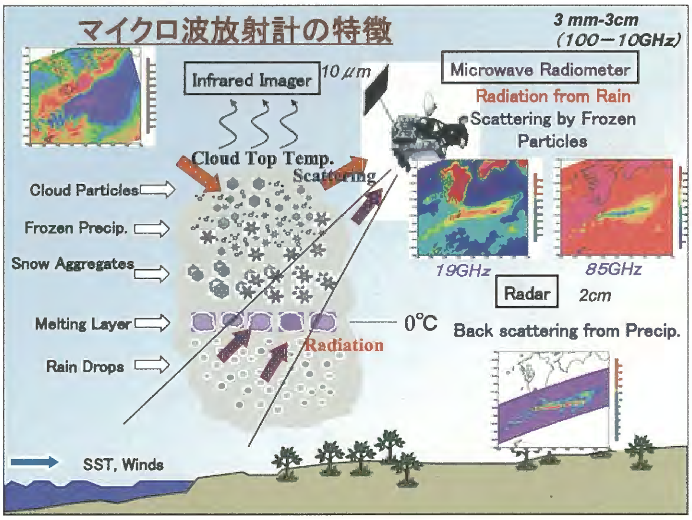
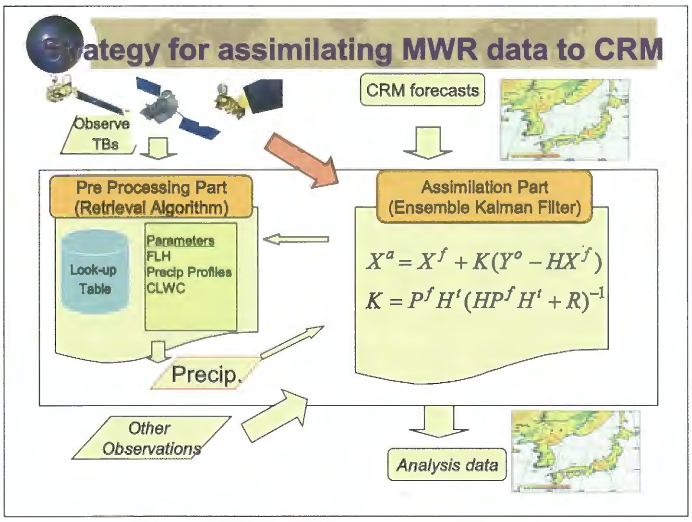
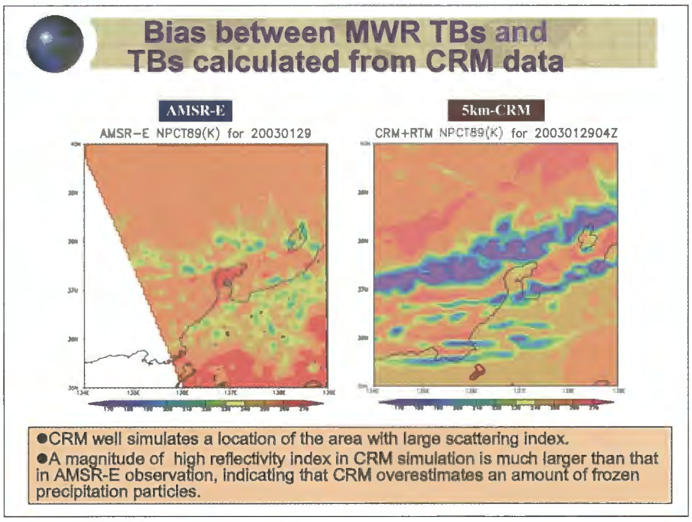
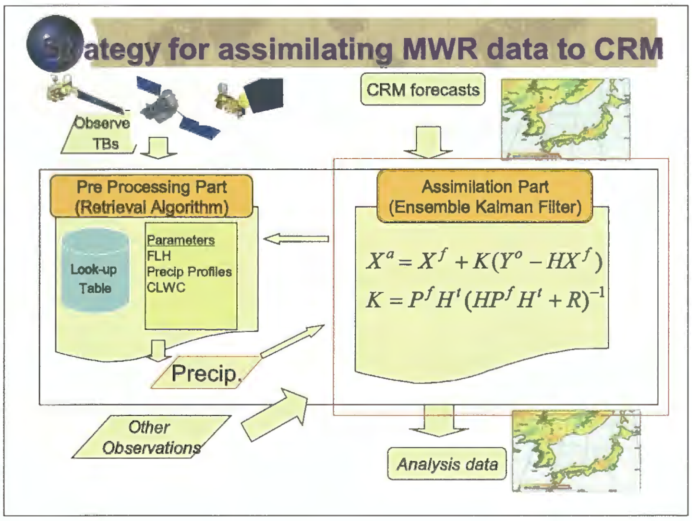
多波長マイクロ波放射計データを用いた水物質リトリーバルの研究　：
マイクロ波放射計データの非静力雲解像モデルへの同化法の開発

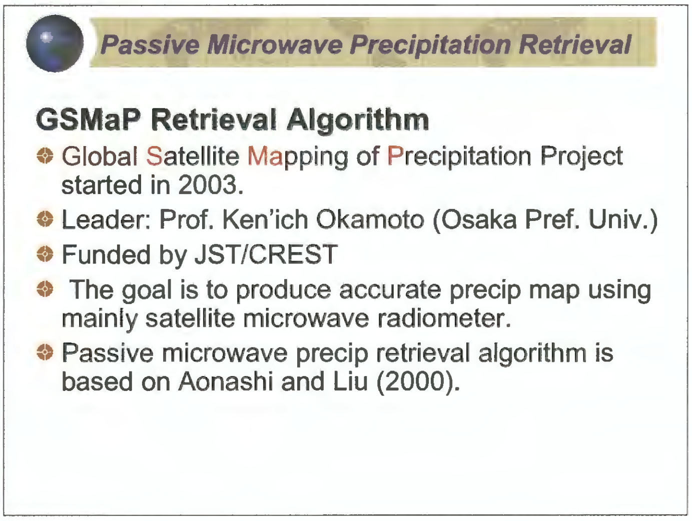






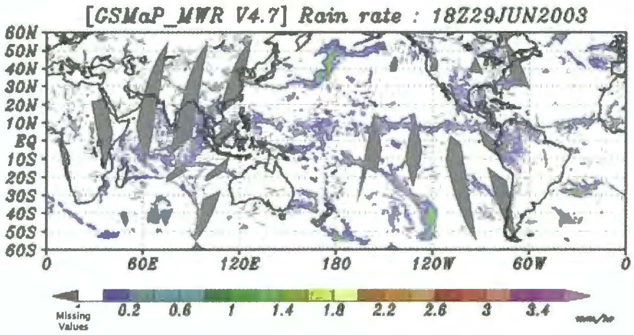






Integrated 6-hour Microwave radiometer Precipitation Map

(TMI+AMSR+AMSR-E+F13,F14,F15 SSM/I; Jul., 2003)



Outline

- Introduction
- EnKF Scheme
- Forecast Error Correlation between Precipitation and CRM variables
- Preliminary results of Assim. Experiment
- Summary

$$X^a = X^f + K(Y^o - HX^f)$$

$$K = P^f H^t (HP^f H^t + R)^{-1}$$

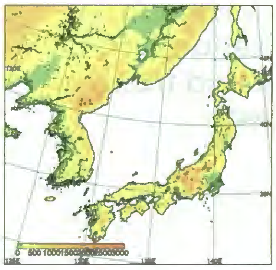
Data Assimilation Method

EnKF scheme

Cloud-Resolving Model used

JMANHM (Saito et al,2001)

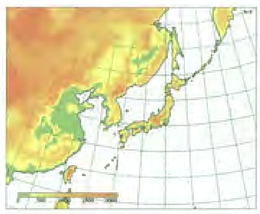
- Resolution: 5 km
- Grids: 400 x 400 x 38
- Time interval: 15 s



Initial and boundary data

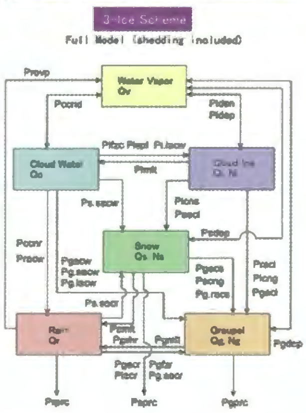
RSM (JMA's operational regional model)

- **Basic equations :** Hydrostatic primitive
- **Precipitation scheme:**
  Moist convective adjustment
  + Arakawa-Schubert
  + Large scale condensation
- **Resolution:** 20 km
- **Grids:** 257 x 217 x 36



Cloud Microphysical Scheme

- Explicit cloud microphysics scheme based on bulk method *(Lin et al.,1983; Murakami, 1990; Ikawa and Saito, 1991)*
- The water substances are categorized into 6 water species *(water vapor, cloud water, rain, cloud ice, snow and graupel)*
- Explicitly predicting the mixing ratios and the number concentrations



Ensemble Kalman Filter (EnKF)

- Kalman Filter: $X^a = X^f + K(Y^o - HX^f)$
  where K $K = P^f H^t (HP^f H^t + R)^{-1}$
- EnKF: use ensemble to estimate forecast error covariance $P^f H^t$ $HP^f H$:

$$P^f H^t = \frac{1}{N-1}\sum_{n=1}^{N}(X_n^f - \overline{X}_n^f) * (H(X_n^f) - H(\overline{X}_n^f))$$

$$HP^f H^t = \frac{1}{N-1}\sum_{n=1}^{N}(H(X_n^f) - H(\overline{X}_n^f)) * (H(X_n^f) - H(\overline{X}_n^f))$$

Ensemble Square root Filter (EnSRF)
Snyder & Zhang(2003)

- Compute analyses for ensemble average $\overline{X}^a$ and each member $X_n^a = \overline{X}^a + \delta X_n^a$

$$\overline{X}^a = \overline{X}^f + WK(Y^o - H(\overline{X}^f))$$

$$\delta X_n^{\ a} = \delta X_n^{\ f} - WK\beta H \delta X_n^{\ f},$$

$$\beta = (1 + \sqrt{R/(HP^f H^t + R)})^{-1}$$

- where W is the localization weight

Ensemble Forecast (Mitchell et al, 2002)

- 100 members started with perturbed initial data:

$$X_i(t_0) = X_c(t_0) + \delta X_i$$

- Geostrophically-balanced perturbation δX_i
- 3D perturbation in stream function ψ
  XY : 2D random fields with correlation

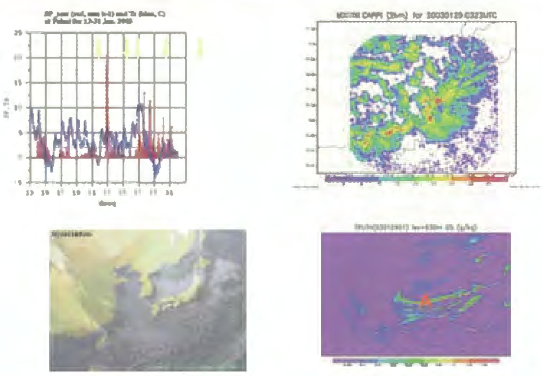
  $correlation\ \rho(r) = (1 + (r/R)) * \exp(-(r/R))$

  R=1000,300,100,30,10 km (20 members)
  Z : sin (mπz*/H) m=1,3,5 (34, 33, 33 members)
- ψ to perturbation in (θ, u, v, Ps), assuming geostrophic and hydrostatic balance.
- Total energy of perturbation
  SD of PT ~ 1 K

Data Assimilation Method

Forecast Error Correlation between Precipitation and CRM variables calculated from ensemble forecasts

Upper Cold Low case (Jan. 28-29, 2003)

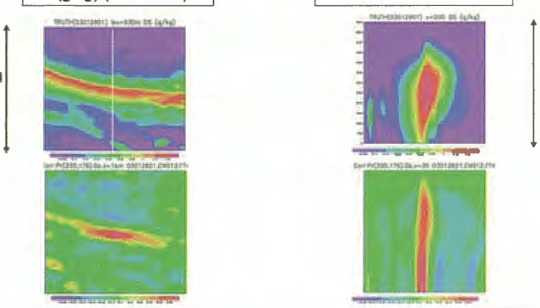


Correlation with Precip at A(200,176)
4 hour forecast (21UTC Jan.28, 2003)

Qs (g/kg) (lev=930m)

vertical cross section Qs

200km



6 km

Corr.Qs (lev=930m)

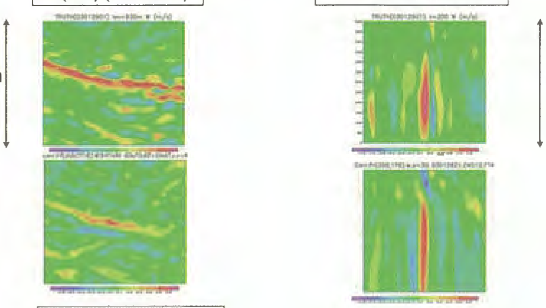
Corr.Qs (cross section)

Correlation with Precip at A(200,176)
4 hour forecast (21UTC Jan.28, 2003)

W (m/s) (lev=930m)

vertical cross section W

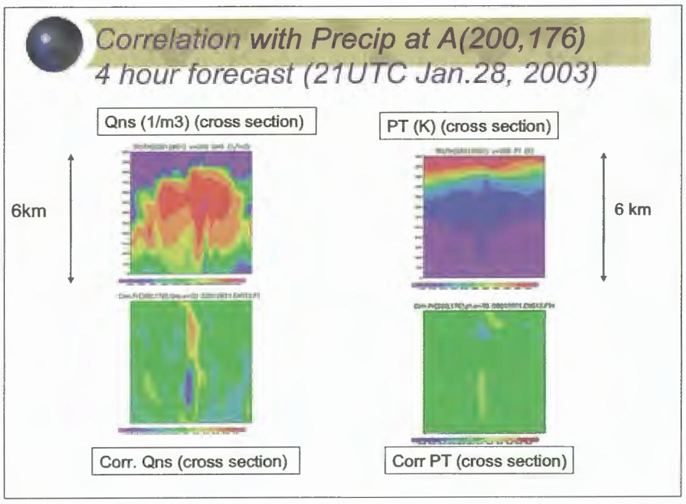
200km

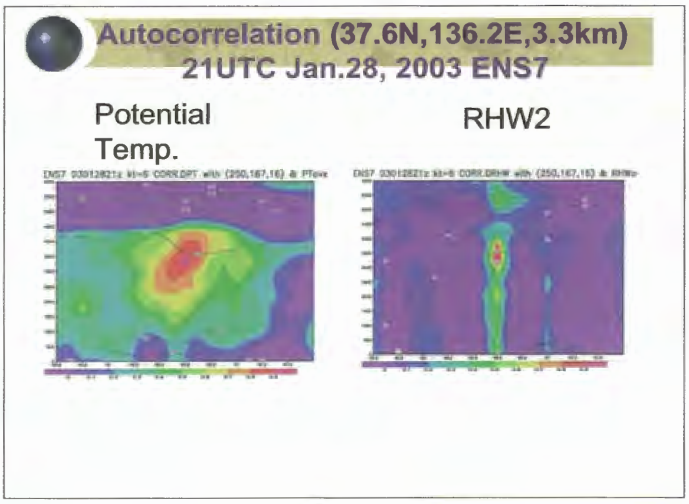


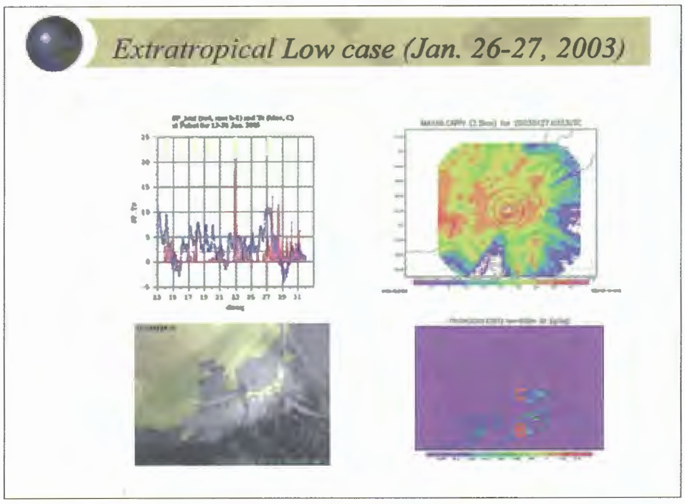
6 km

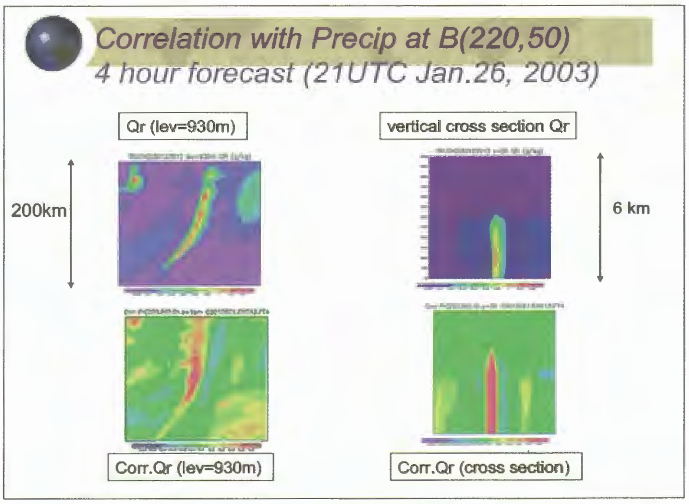
Corr.W (lev=930m)

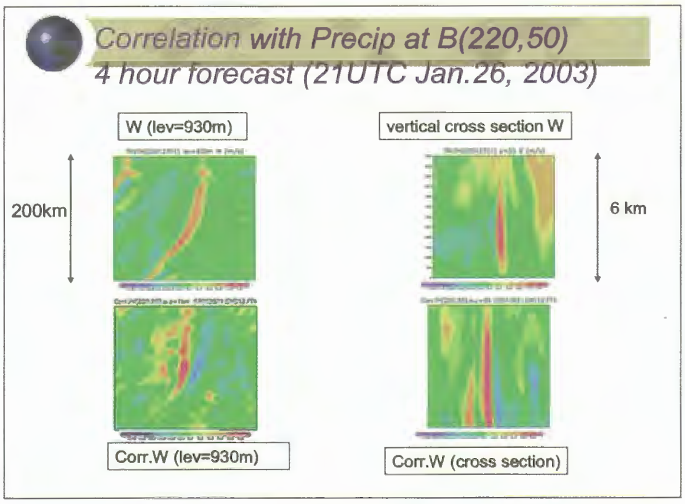
Corr. W (cross section)

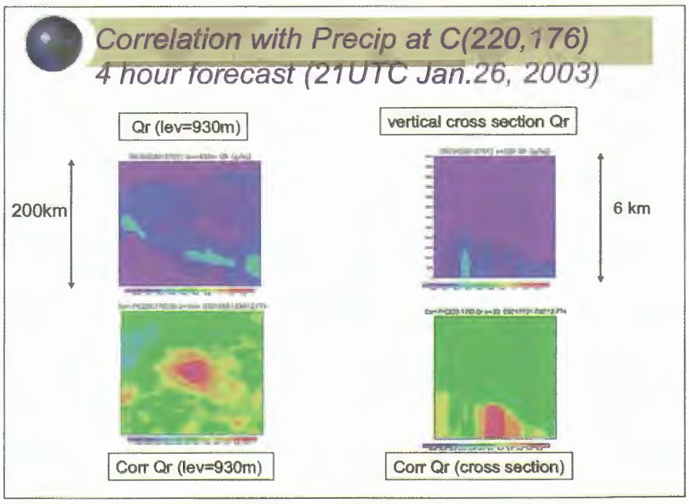

Correlation with Precip at A(200,176)
4 hour forecast (21UTC Jan.28, 2003)
Qns (1/m3) (cross section)
PT (K) (cross section)
6km
6 km
Corr. Qns (cross section)
Corr PT (cross section)


Autocorrelation (37.6N,136.2E,3.3km)
21UTC Jan.28, 2003 ENS7
Potential
Temp.
RHW2

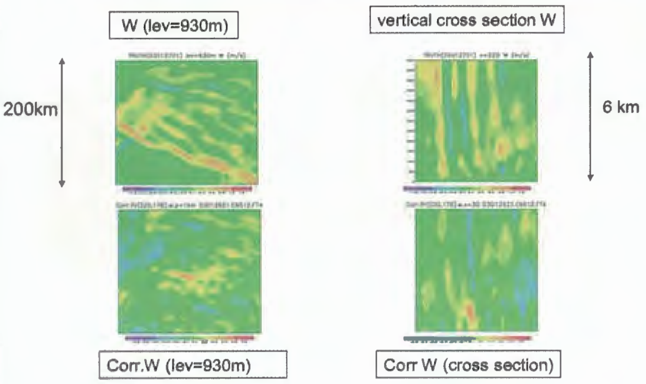

Extratropical Low case (Jan. 26-27, 2003)


Correlation with Precip at B(220,50)
4 hour forecast (21UTC Jan.26, 2003)
Qr (lev=930m)
vertical cross section Qr
200km
6 km
Corr.Qr (lev=930m)
Corr.Qr (cross section)


Correlation with Precip at B(220,50)
4 hour forecast (21UTC Jan.26, 2003)
W (lev=930m)
vertical cross section W
200km
6 km
Corr.W (lev=930m)
Corr.W (cross section)


Correlation with Precip at C(220,176)
4 hour forecast (21UTC Jan.26, 2003)
Qr (lev=930m)
vertical cross section Qr
200km
6 km
Corr Qr (lev=930m)
Corr Qr (cross section)

Correlation with Precip at C(220,176) 4 hour forecast (21UTC Jan.26, 2003)



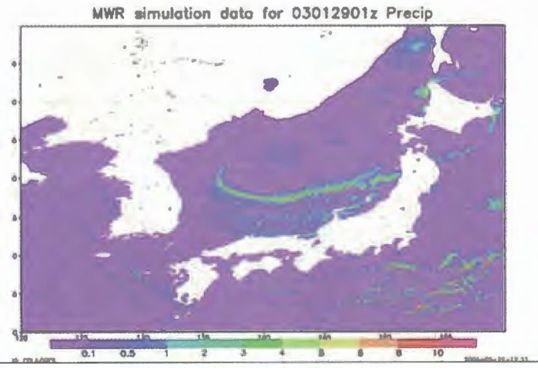
Data Assimilation Method

Preliminary results of Experimental Assimilation

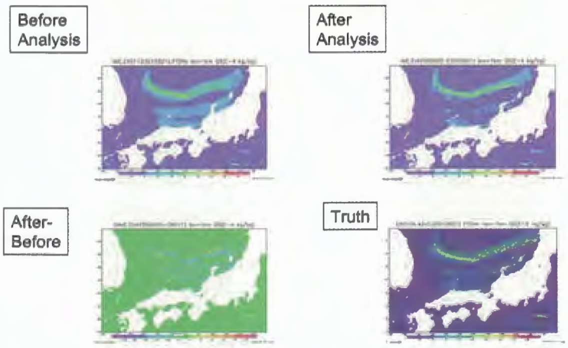
EnKF experiment

- Upper cold low case (Jan. 28-29,2003)
- Ensemble forecast (21 UTC Jan.28, 2003)
  (100 members, same as the previous section)
- Assimilate simulated precipitation data
  (01 UTC Jan. 29, 2003)
- EnKF analysis
  Mixing ratio of rain,snow, & graupel
  RHW2: (qv+qc+qci)/qvs
  Number concentration of snow & graupel
  u,v,w
  W = 0 (distance > 60 km)

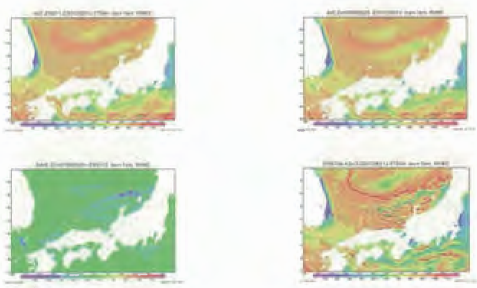
Simulated Precip data for 03/1/29/01UTC: CRM control +perturbation (1/28/21UTC)+ Noise(50%)

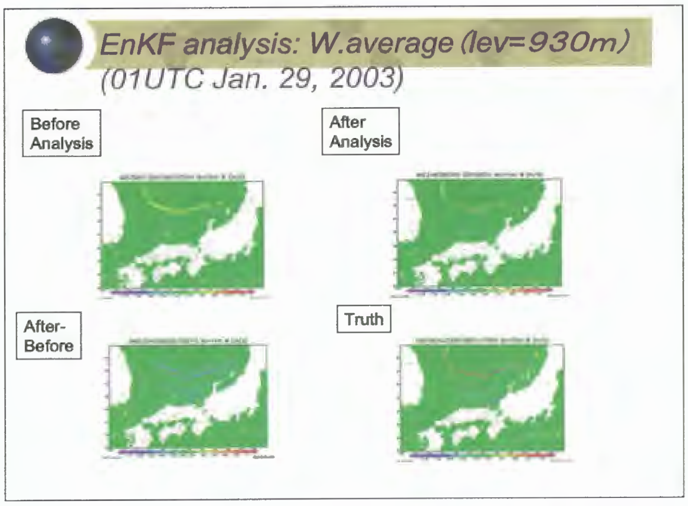


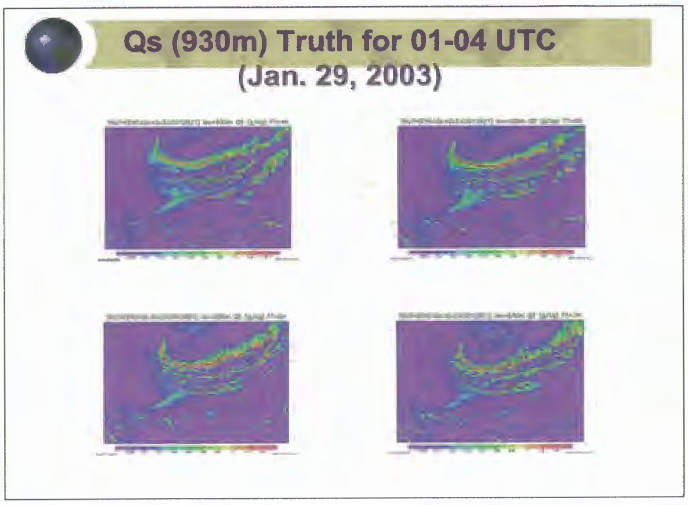
EnKF analysis: Qs.average (lev=930m) (01UTC Jan. 29, 2003)

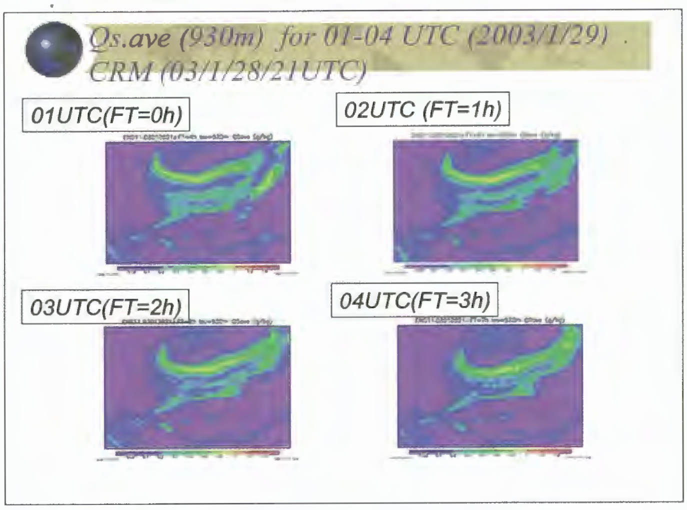


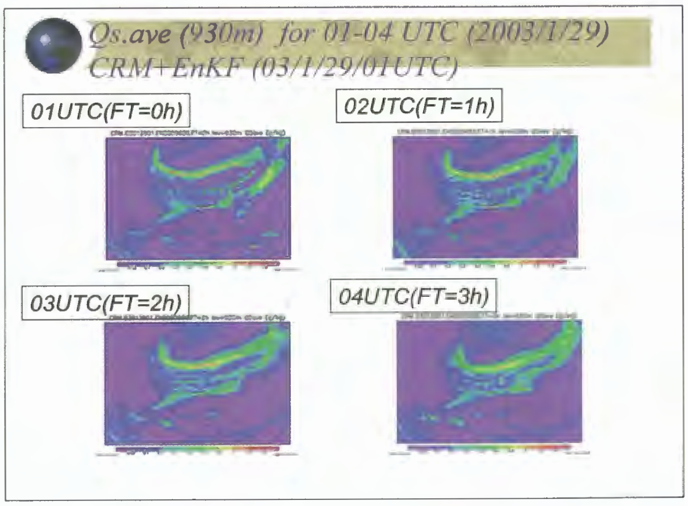
EnKF analysis: RHW2.average (lev=930m) (01UTC Jan. 29, 2003)

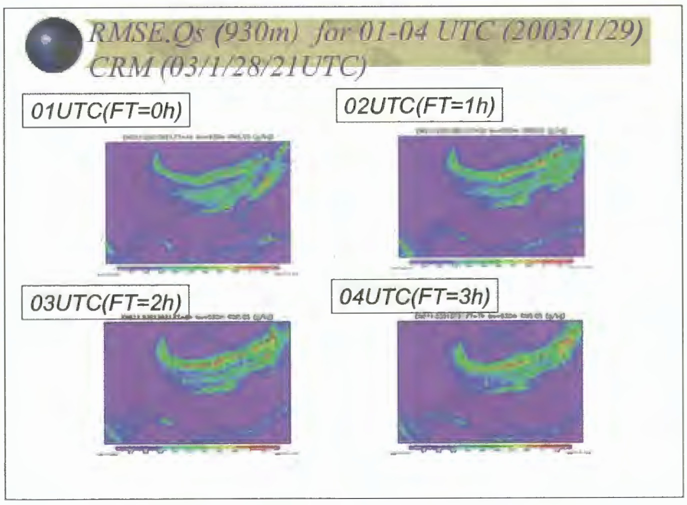


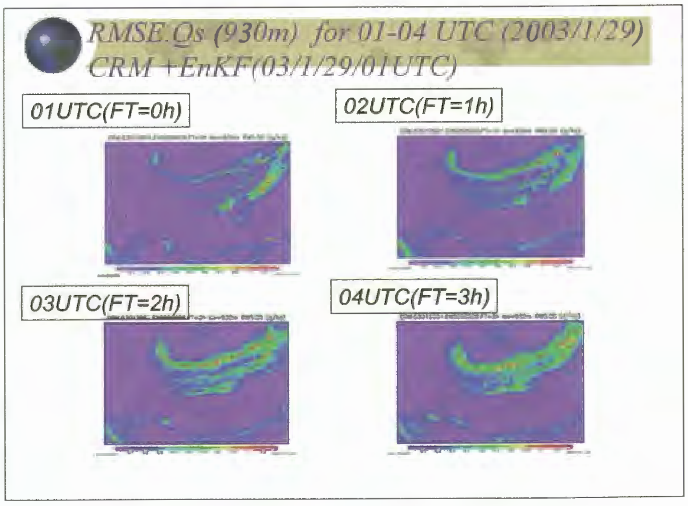

EnKF analysis: W.average (lev=930m)
(01UTC Jan. 29, 2003)
Before Analysis
After Analysis
After-Before
Truth


Qs (930m) Truth for 01-04 UTC
(Jan. 29, 2003)


Qs.ave (930m) for 01-04 UTC (2003/1/29)
CRM (03/1/28/21UTC)
01UTC(FT=0h)
02UTC (FT=1h)
03UTC(FT=2h)
04UTC(FT=3h)


Qs.ave (930m) for 01-04 UTC (2003/1/29)
CRM+EnKF (03/1/29/01UTC)
01UTC(FT=0h)
02UTC(FT=1h)
03UTC(FT=2h)
04UTC(FT=3h)

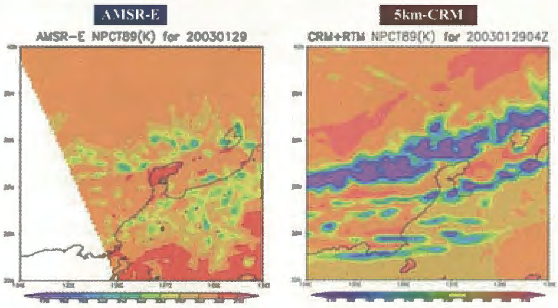

RMSE.Qs (930m) for 01-04 UTC (2003/1/29)
CRM (03/1/28/21UTC)
01UTC(FT=0h)
02UTC(FT=1h)
03UTC(FT=2h)
04UTC(FT=3h)


RMSE.Qs (930m) for 01-04 UTC (2003/1/29)
CRM +EnKF(03/1/29/01UTC)
01UTC(FT=0h)
02UTC(FT=1h)
03UTC(FT=2h)
04UTC(FT=3h)

Summary

- We have developed Ensemble Square Root Filter (SRF) scheme.
- Precipitation rate had large forecast error correlations with vertical wind speed, as well as the mixing ratio of cloud physical variables.
- Large flow-dependent variations in forecast error correlations were found.
- Results from preliminary experiments using simulated precipitation data show that the EnKF is successful in retrieving the cloud-physical variables and vertical wind speed.

Bias between MWR TBs and TBs calculated from CRM data



- CRM well simulates a location of the area with large scattering index.
- A magnitude of high reflectivity index in CRM simulation is much larger than that in AMSR-E observation, indicating that CRM overestimates an amount of frozen precipitation particles.

Thank you for your attention.