Simple Doppler Wind Lidar (DWL) adaptive observation experiments with a global model

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Jan. 17, 2007
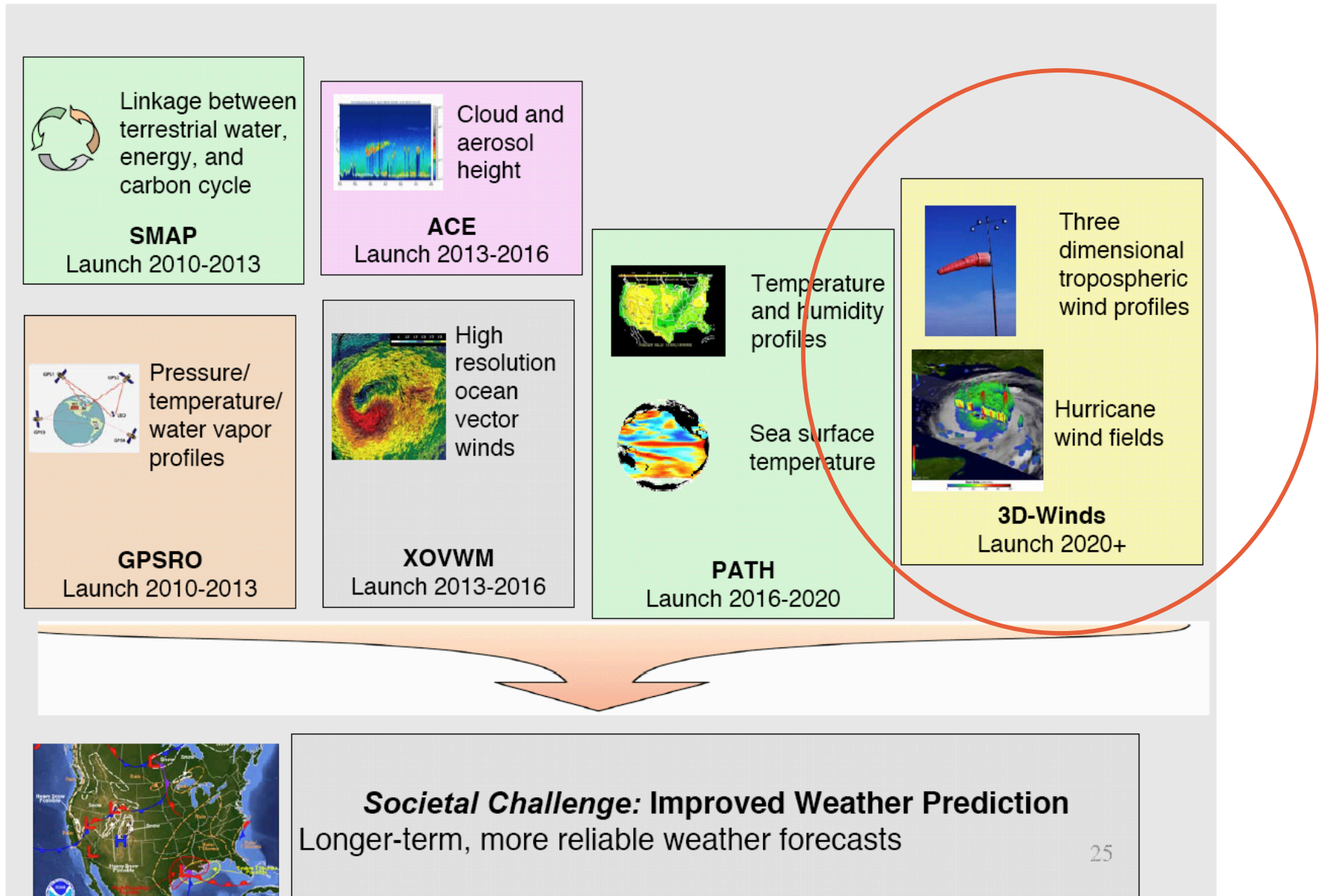
Background

- Lack of wind observations is a major factor for NWP uncertainty, especially over tropics and ocean.

- Future Doppler Wind Lidar (DWL, Stoffelen et al., 2005; "Earth Science and Applications from Space National Imperatives for the Next Decade and Beyond" recommendations) will provide much denser wind profile observations. To optimize the investment output, DWL could operate in adaptive targeting mode.

- How to allocate these observation resources (e.g., 10% of the time) is a central issue to maximize effectiveness of DWL observations.

# Decadal Study Recommendations (AMS 2007)

Ensemble spread adaptive observation strategy

- Ensemble spread estimated from ensemble Kalman filter (EnKF) reflects the dynamical uncertainties related with background dynamic flow.

- In EnKF the ensemble spread strategy is very simple: we add the adaptive observations where the ensemble spread is large.

Background: ensemble spread adaptive strategy in Lorenz-40 variable model

10-day forecast RMS error of Lorenz-40 variable model
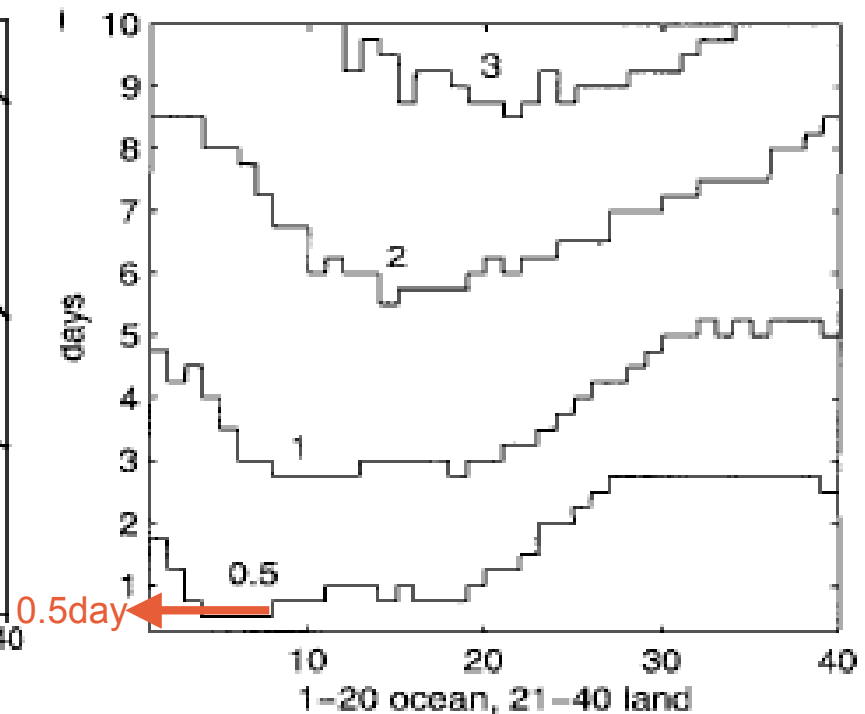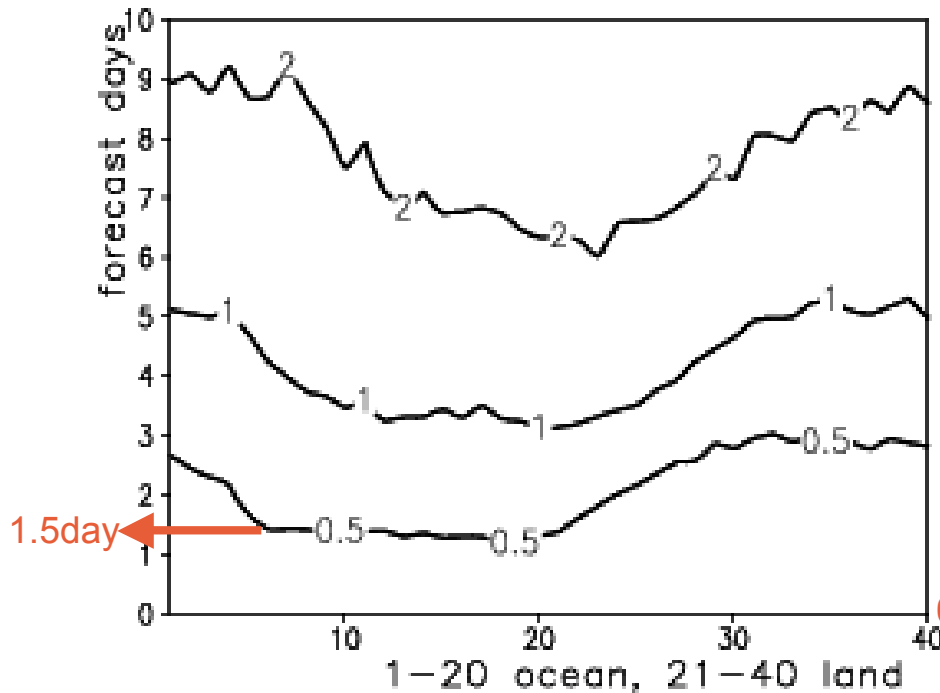
Ensemble spread method with 15 ensemble-member LETKF (Liu et al., 2006)

Singular vector method with 1024 ensemble-member EnKF (Hansen and Smith, 2000)

Ensemble spread sampling strategy with 15-member LETKF gives better results than singular vector method with a 1024 ensemble-member EnKF scheme

Questions

- How effective is the ensemble spread sampling strategy compared to other sampling strategies (random picking, uniform distribution, ideal sampling (knowing the truth), and climatology ensemble spread) in a global model with simple experimental setup?

- How much impact can we get if we only observe 10% wind observations instead of 100% (full coverage)?

- How different is the impact from adaptive observation with different data assimilation schemes?

Experimental Design

- SPEEDY model (Molteni, 2003, adapted by Miyoshi, 2005)
  - ➤ A global model with fast computation speed.
  - ➤ 96 grid points horizontally, and 48 grid points meridionally, and 7 vertical levels

- Data assimilation schemes
  - ➤ Local Ensemble Transform Kalman Filter (LETKF, Hunt et al., 2006)
  - ➤ 3D-Var (Miyoshi, 2005)

- Simulated observations
  - ➤ Obtained from "truth" (a long time integration) plus random perturbations.
  - ➤ Basic observation locations are rawinsonde locations, which observe all the dynamical variables.
  - ➤ We observe both zonal and meridional wind at adaptive observation points.

Rawinsonde observation locations and simulated satellite winds scanning range
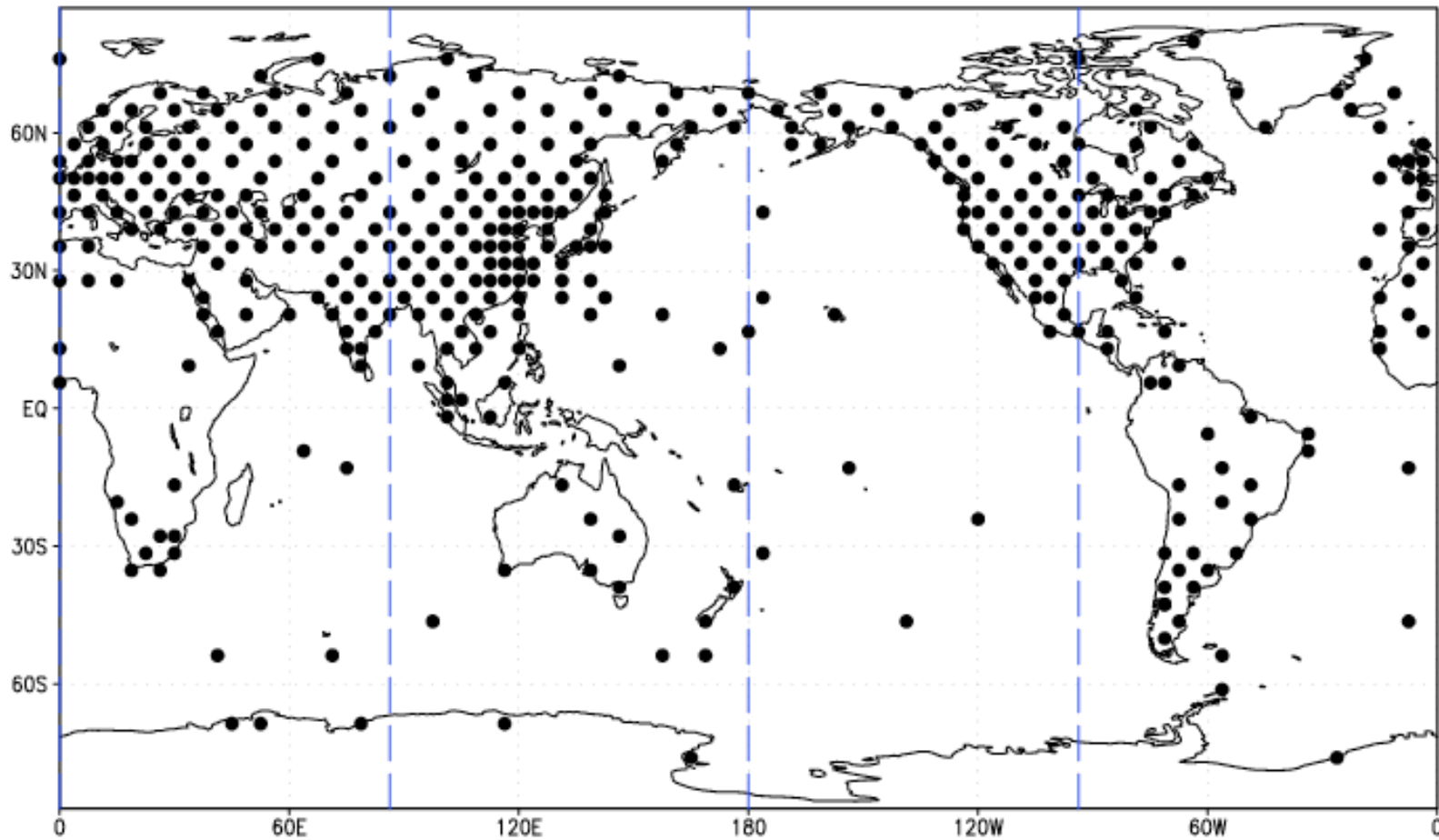
00z and 12z 06z and 18z 00z and 12z 06z and 18z

→ The "orbit" allows simulated DWL observations potentially scanning each location twice a day.

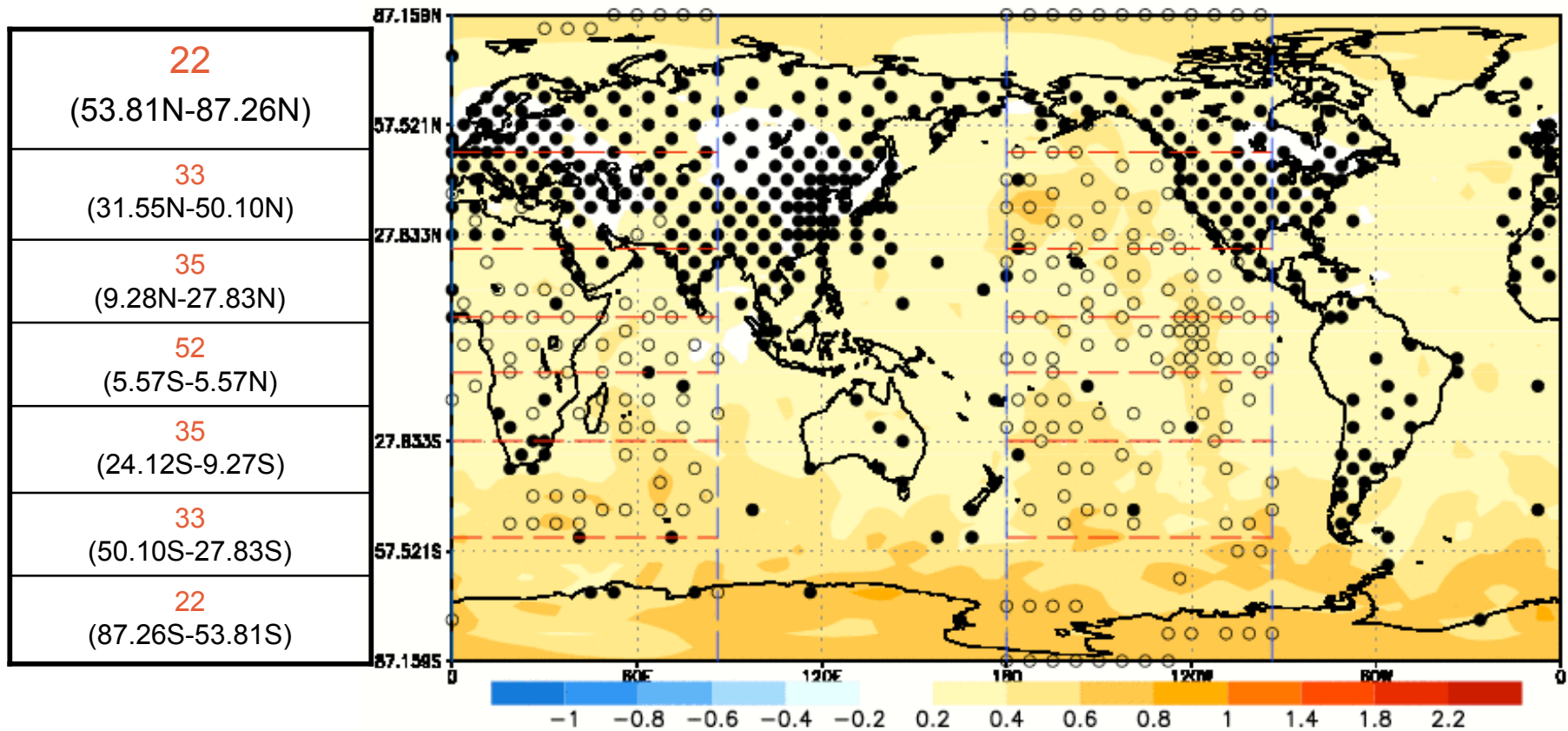→ 10% adaptive observations: 10% of half global grid points.

Sampling strategies

- Ensemble spread strategy (from Local Ensemble Transform Kalman Filter)

  → Adaptive observations are at locations with large ensemble wind spread at 500hPa.

  → 3D-Var and LETKF have the same adaptive observation points

- Random picking

  → Randomly pick locations from potential locations.

- Uniform distribution

  → Uniformly distributed.

- Climatology ensemble spread

  → Adaptive observations are at locations with large climatological average ensemble wind spread from rawinsonde assimilation.

  → Constant with time, and same for 3D-Var and LETKF.

- "Ideal" sampling

  Adaptive observations are at locations with large background error obtained from the "truth".

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10% adaptive observation (open circles) distribution from ensemble spread (shaded area; Unit: m/s) strategy of LETKF
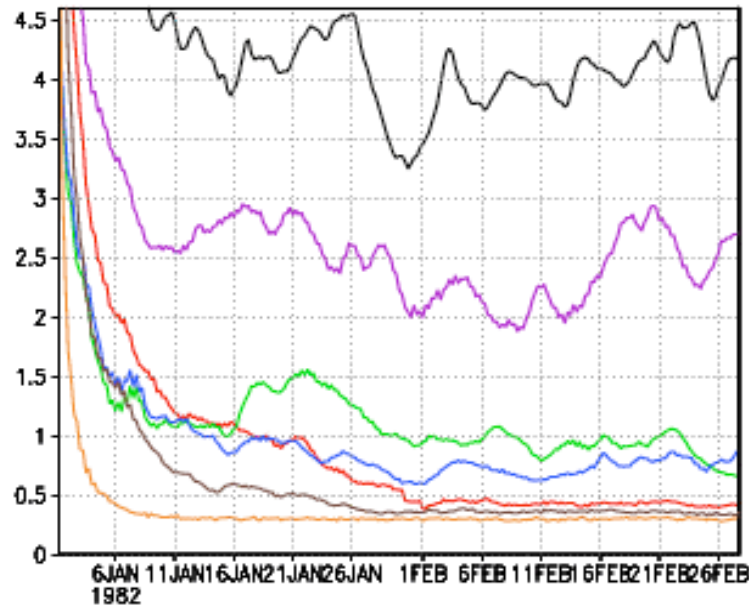

22 (53.81N-87.26N)	
33 (31.55N-50.10N)	
35 (9.28N-27.83N)	
52 (5.57S-5.57N)	
35 (24.12S-9.27S)	
33 (50.10S-27.83S)	
22 (87.26S-53.81S)	

In red: number of adaptive observations in each band separated by red line, proportional to the area of each band.
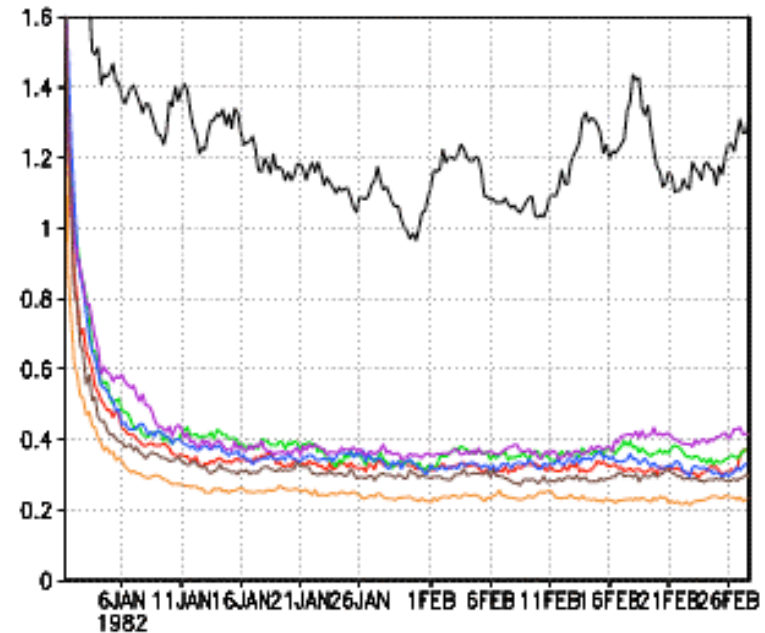
500hPa zonal wind RMS error

Rawinsonde; climatology; uniform; random; ensemble spread; "ideal"; 100%

3D-Var

LETKF

RMSE	4.04	2.36	0.92	0.74	0.43	0.36	0.30		1.18	0.38	0.36	0.33	0.32	0.29	0.23

➤ With 10% adaptive observations, the analysis accuracy is significantly improved for both 3D-Var and LETKF.

➤ 3D-Var is more sensitive to adaptive strategies than LETKF. Ensemble spread strategy gets best result among operational possible strategies
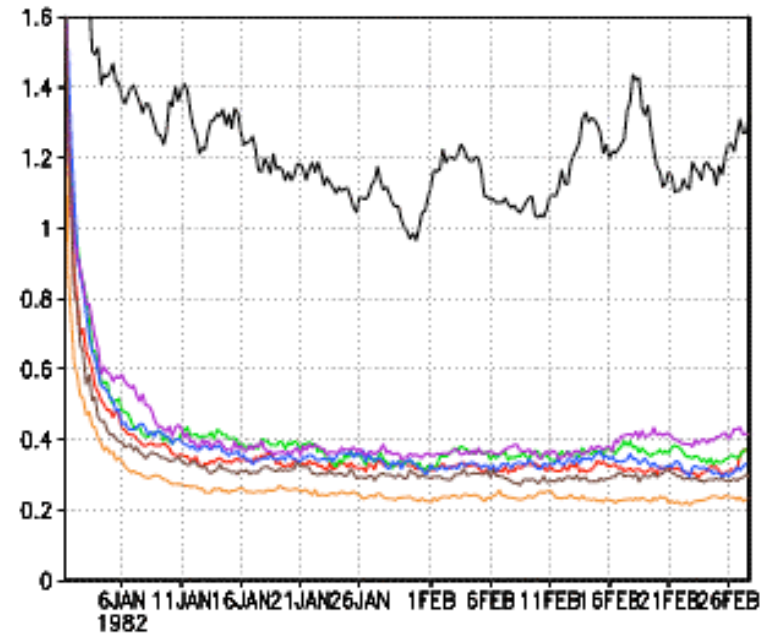
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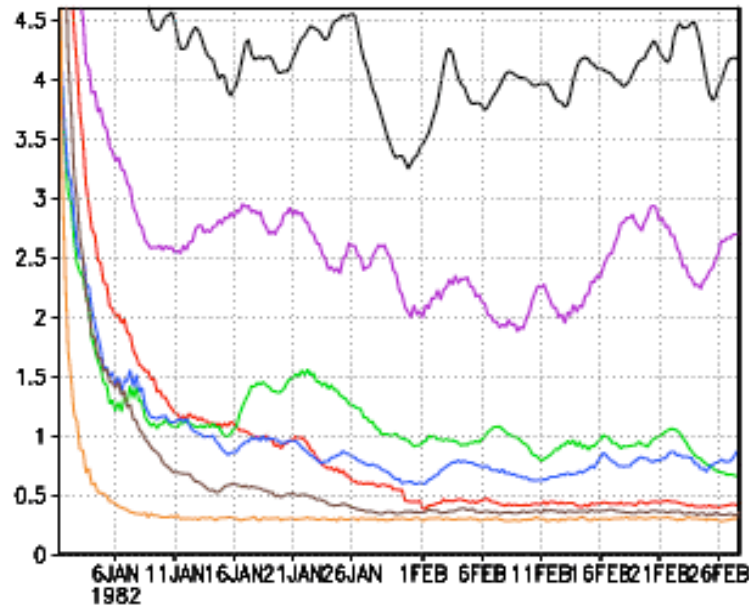| RMSE	4.04	2.36	0.92	0.74	0.43	0.36	0.30

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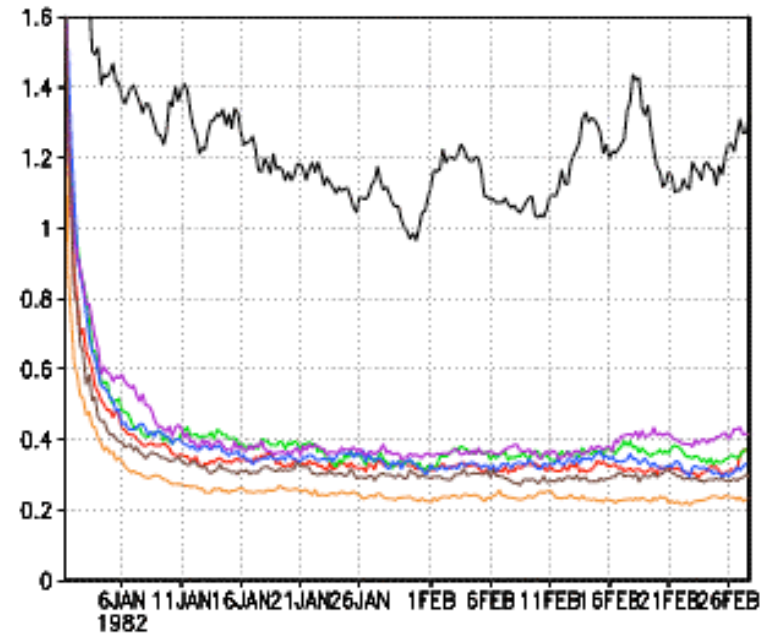
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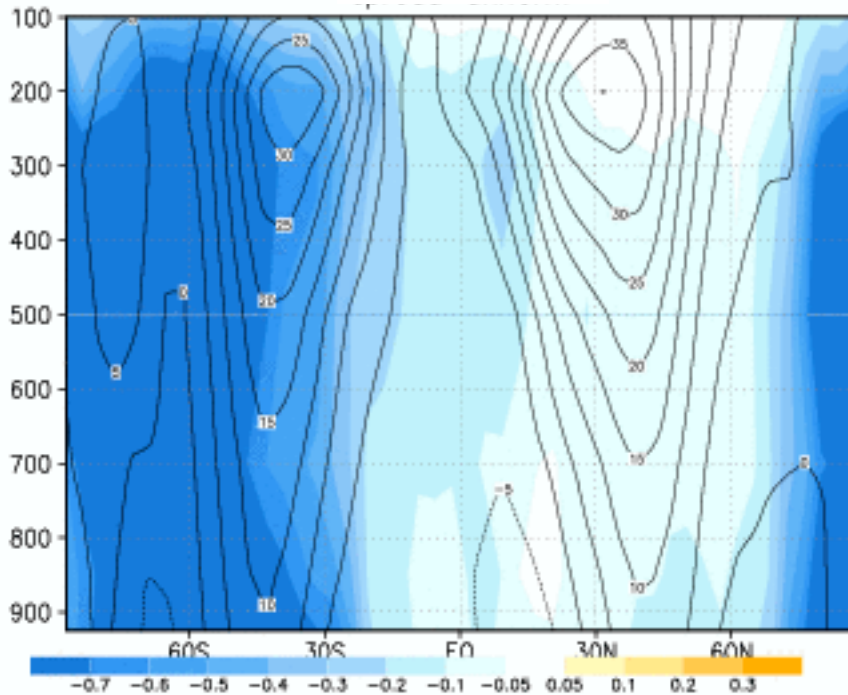
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The zonal mean RMS error difference between ensemble spread strategy and uniform distribution for zonal wind
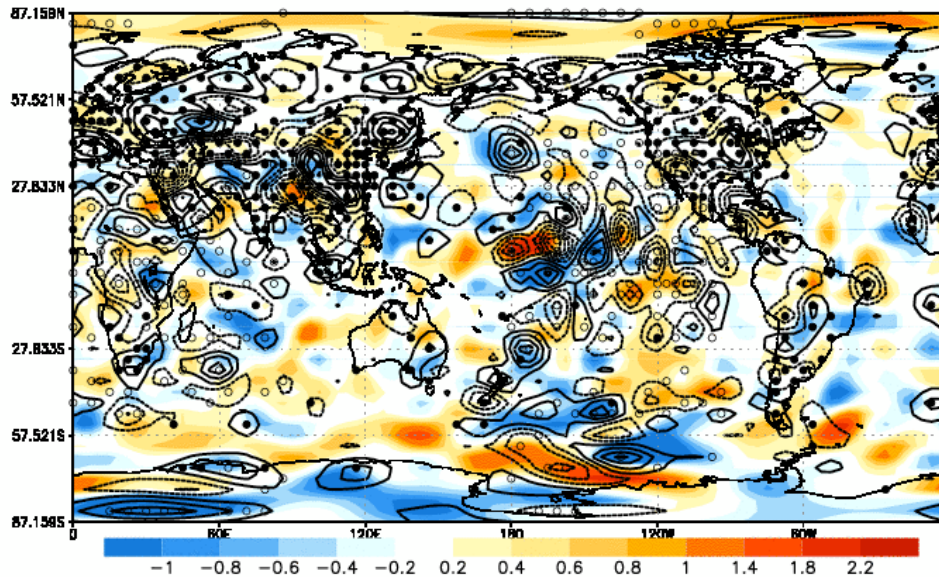
3D-Var

LETKF
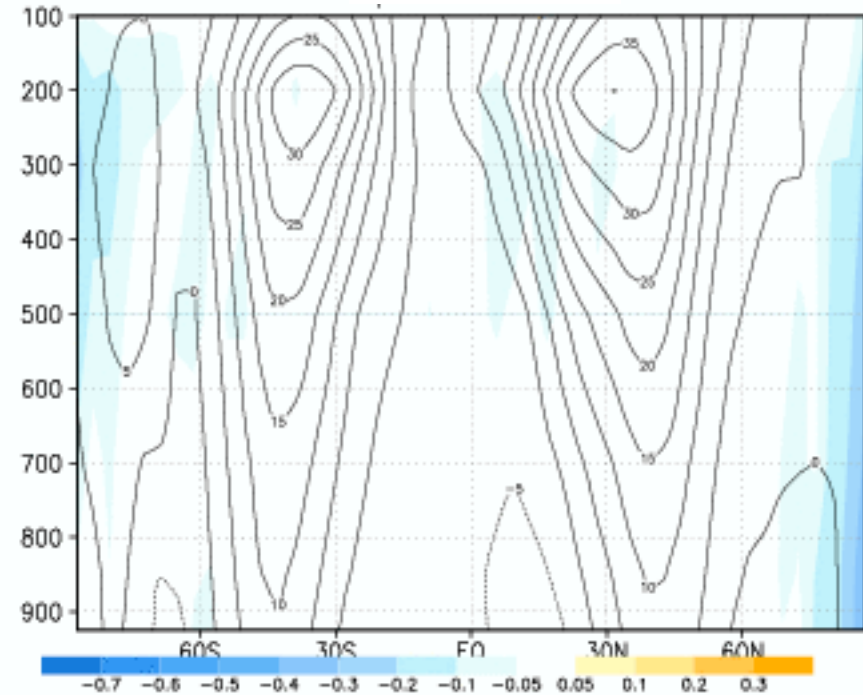
> ➢ 3D-Var shows much more significant difference between different strategies than that of LETKF.

> ➢The largest differences between different adaptive strategies with 3D-Var is over data sparse regions since there the adaptive observations have most impact.
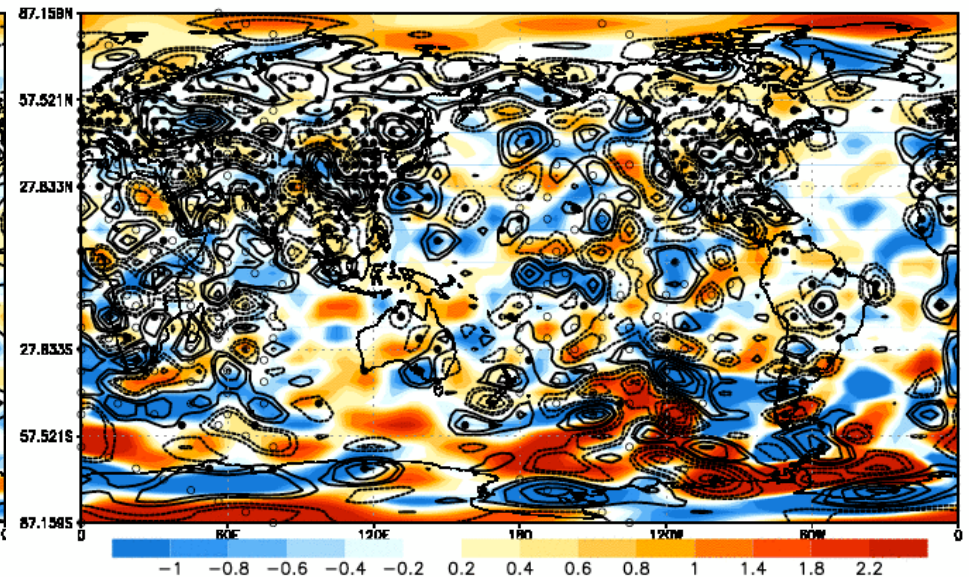
Analysis increment (contour, Unit: m/s, interval: 0.2m/s), background error (shaded, Unit: m/s), and adaptive observation locations (open circles)

3D-Var

Ensemble spread sampling strategy

Uniform distribution

➤Analysis increment of 3D-Var is centered around observation locations.

➤With adaptive observations from ensemble spread sampling strategy, analysis increment is pretty consistent with background error, like introducing the time-changing background error.

➤With adaptive observation with uniform distribution, analysis increment is not consistent with background error.
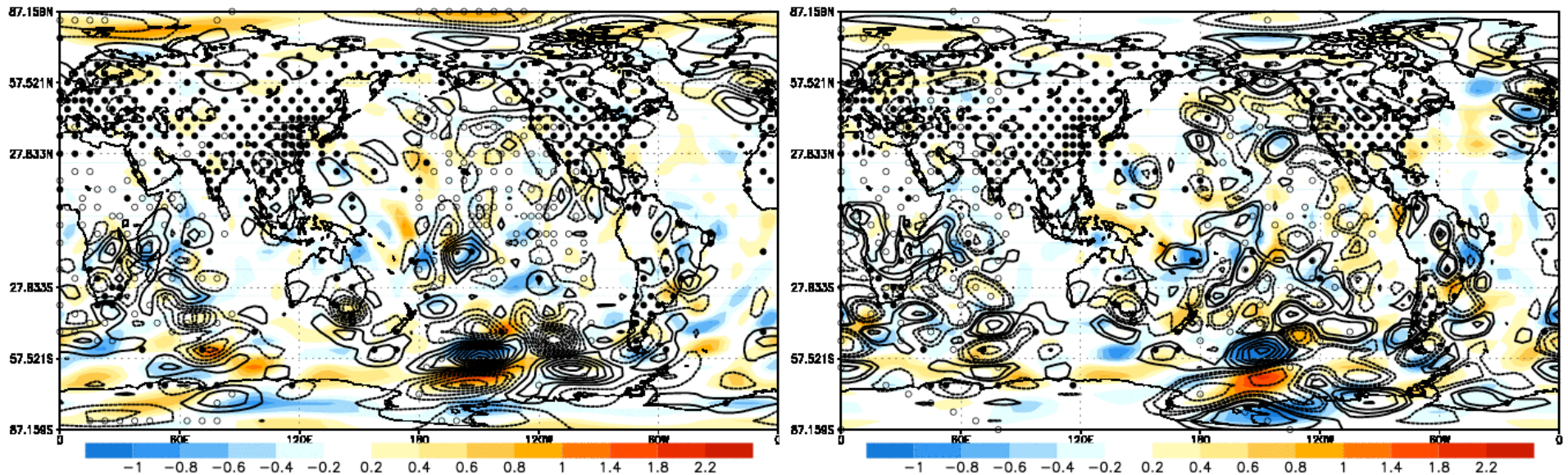
Analysis increment (contour, Unit: m/s, interval: 0.1m/s), background error (shaded, Unit: m/s), and adaptive observation locations (open circles)

LETKF

Ensemble spread sampling strategy   Uniform distribution

➤Analysis increment of LETKF is not centered around observation locations, but line along background error

➤Analysis increments from both ensemble spread sampling strategy and uniform distrition are consistent with background error
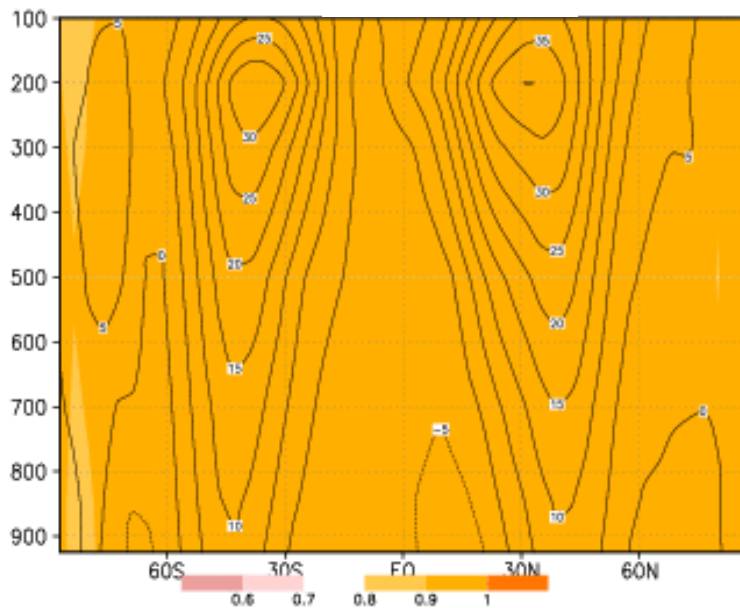
- What percentage improvement do we get from 10% adaptive observations compared with 100% adaptive observations?

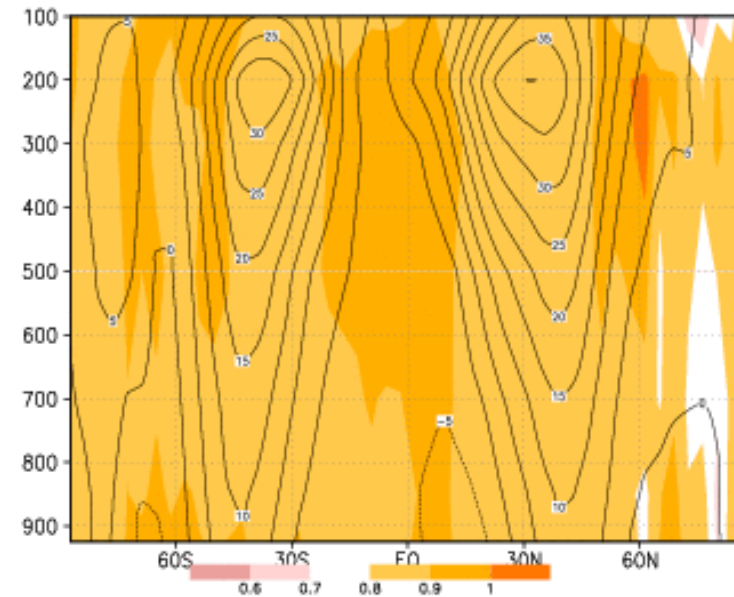$$B = \frac{RMS(10\%) - RMS(rawinsonde)}{RMS(100\%) - RMS(rawinsonde)}$$

Percentage effectiveness of 10% adaptive observation

Ensemble Spread

3D-Var

LETKF

➢ With ensemble spread, 10% adaptive observation can get more than 90% effect of 100% observation with 3D-Var.

➢ The percentage effectiveness is more than 80% most of area with LETKF because it already accounts for "errors of the day"

Conclusions and discussion

- In 3D-Var, analysis corrections are isotropic, and centered around observation locations. This makes 3D-Var very sensitive to adaptive observation locations.

- In LETKF, the analysis corrections follow the background errors, so LETKF is not sensitive to observation locations with 10% adaptive wind observations.

- The best adaptive strategy in 3D-Var is ensemble spread. The reason is that ensemble spread reflects the dynamical uncertainty, which is telling 3D-Var where are the "errors of the day".

- With ensemble spread in 3D-Var, 10% adaptive observation can get over 90% effect of full coverage over half the globe. With every method (ensemble spread, uniform, random), LETKF can get more 80% improvement from 10% adaptive observations.

➔ We will further to examine the robustness of the result with more realistic experimental setup.