Ensemble Forecast Sensitivity to Observations (EFSO) technique for global OSEs

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Summary

- ✓ An AGCM-LETKF data assimilation system, ALERA2, can be used for global observing system experiments (OSEs) to evaluate impacts of specific observation in the global observing system to synoptic–large-scale atmospheric circulations.
- ✓ Ensemble-based Forecast Sensitivity to Observations (EFSO) quantitatively well estimated impacts of individual observations (ex. observation campaign) by comparing actual data denial experiments or OSEs.
- ✓ Radiosonde observations whose impacts were more propagated into the Arctic give the larger impact on weekly weather forecasting in the ALERA2 system.

1. Introduction

AFES-LETKF ensemble data assimilation system & global reanalysis (ALERA2)

ALERA2 configurations	
Model	AFES (Atmospheric GCM) T119L48 (~1° × 1°, up to ~3 hPa)
DA scheme	LETKF
Ensemble size	63
Observations	Conventional + satellite wind (NCEP PREPBUFR)
DA window	6 hour
Ocean	Daily ¼ OISSTICE
References	Miyoshi & Yamane (2007 *MWR*); Enomoto et al. (2013); Yamazaki et al. (2017 *SOLA*)

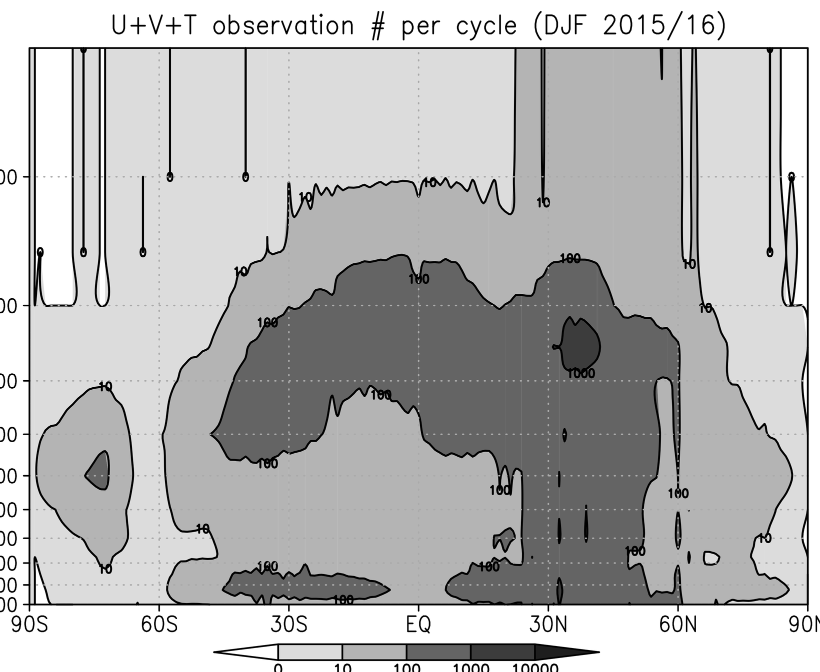


Fig.1: Latitude-height distribution of number of U, V, and T observations [per cycle] during Dec–Feb (DJF) of 2015/16.

(Re)analysis period and streams of ALERA2 (http://www.jamstec.go.jp/alera/alera2.html).

ALERA2 for Observing system (data denial) experiments

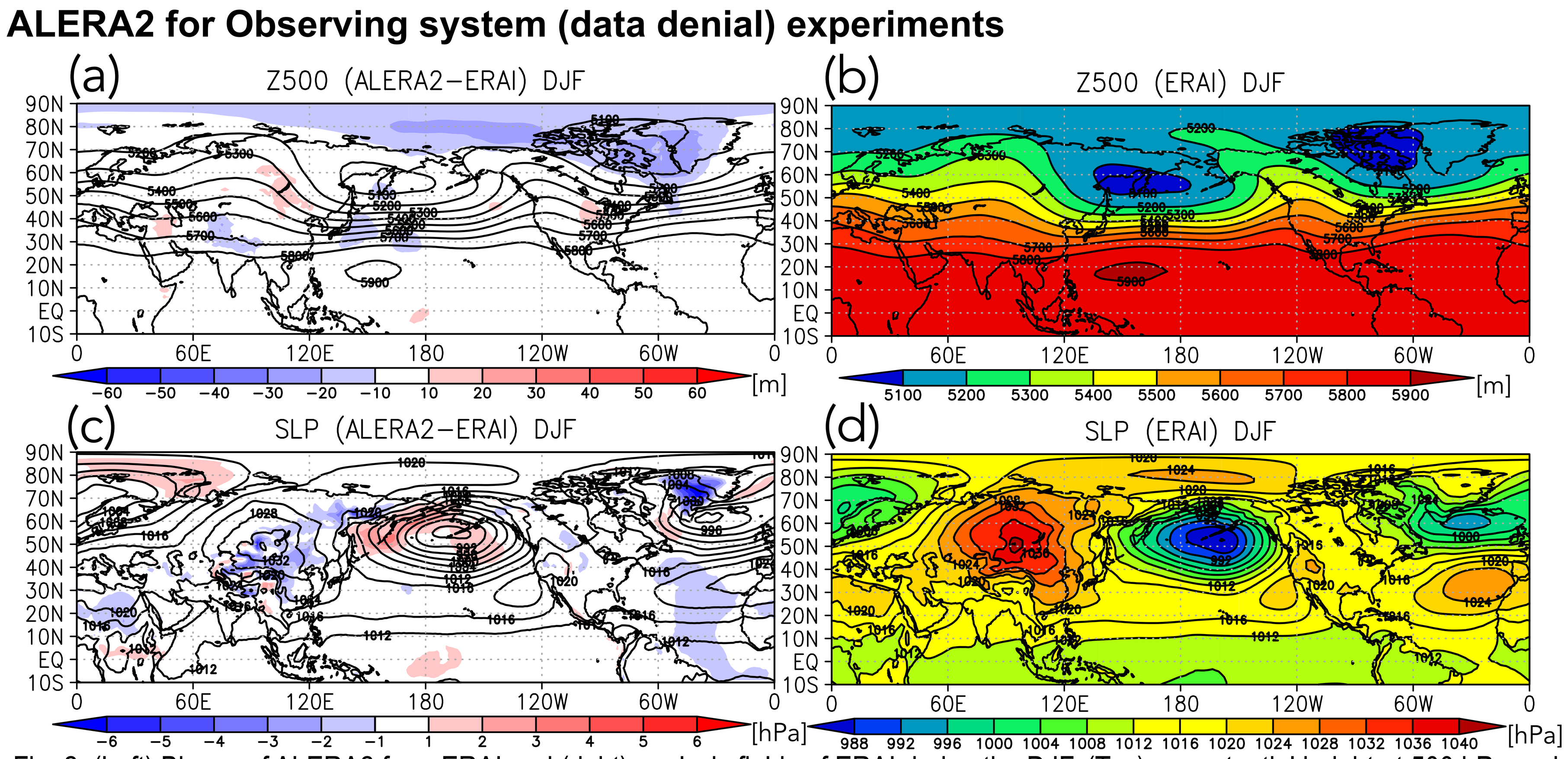


Fig. 2: (Left) Biases of ALERA2 from ERAI and (right) analysis fields of ERAI during the DJF. (Top) geopotential height at 500 hPa and (bottom) SLP.

- ✓ ALERA2 can reproduce realistic wintertime synoptic–large-scale atmospheric circulations.
- ✓ ALERA2 and the DA system have been successfully used for OSEs to estimate impacts of special observation campaigns to investigate, e.g., how much specific radiosondes improved forecasts of cyclones, and how did their impacts dynamically propagate (e.g., Yamazaki et al. 2015 *JGR-A*; Sato, Inoue, Yamazaki, et al. 2018 *Sci. Rep.*).
- ■ OSEs are expensive to conduct additional data assimilation cycles and forecasts.

Implementation of Ensemble-based FSO diagnosis

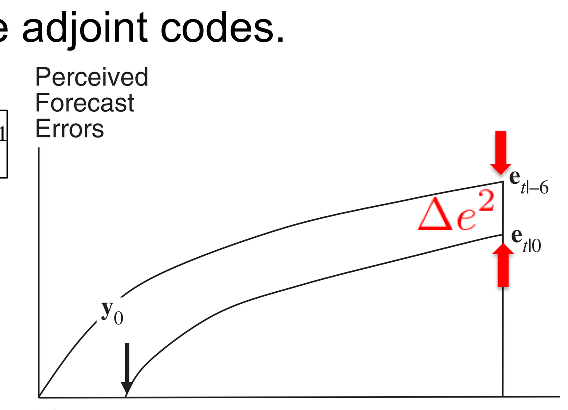
- ✓ Forecast Sensitivity to Observation (FSO) diagnosis enables for the quantification of how much each observation has improved or degraded the forecast without OSEs.
- ✓ Recent studies (e.g., Kalnay et al. 2012 *Tellus*; Hotta et al. 2017 *MWR*) proposed ensemble-based FSO (EFSO) technique without requiring the adjoint codes.

t-hr EFSO impact (Δe^2)

$$\Delta e^2 = \mathbf{e}_{t|0}^{\mathrm{T}}\mathbf{C}\mathbf{e}_{t|0} - \mathbf{e}_{t|-6}^{\mathrm{T}}\mathbf{C}\mathbf{e}_{t|-6}$$
$$\approx [\mathbf{M}_{t|0}\mathbf{K}\delta\bar{\mathbf{y}}_0^{\mathrm{ob}}]^{\mathrm{T}}\mathbf{C}(\mathbf{e}_{t|0}+\mathbf{e}_{t|-6})$$
$$\approx (\delta\bar{\mathbf{y}}_0^{\mathrm{ob}})^{\mathrm{T}}\frac{1}{K-1}\mathbf{R}^{-1}\mathbf{Y}_0^a(\mathbf{X}_{t|0}^f)^{\mathrm{T}}\mathbf{C}(\mathbf{e}_{t|0}+\mathbf{e}_{t|-6})$$

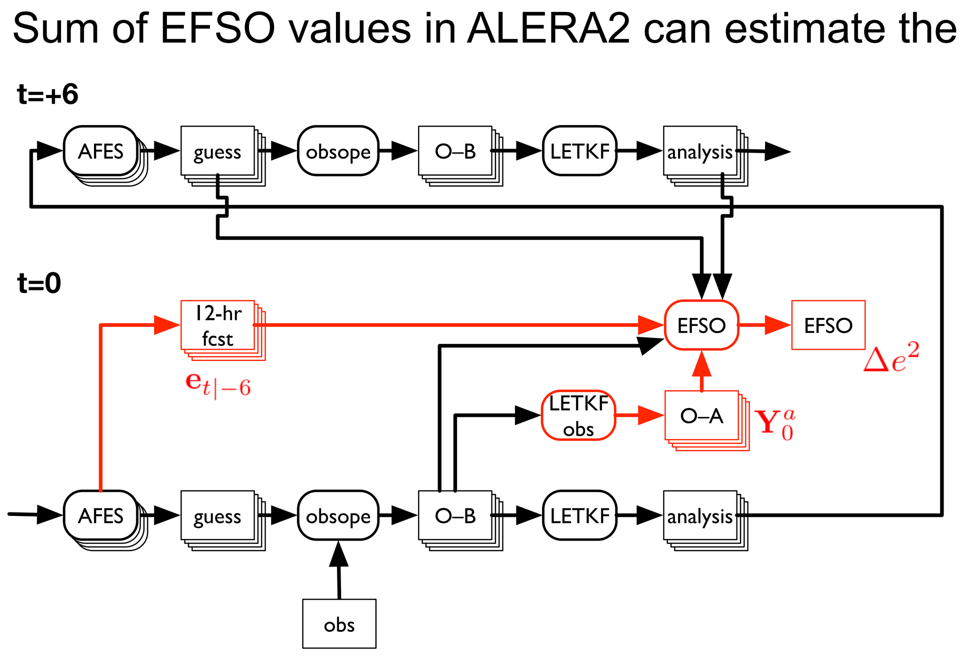
$$\mathbf{K} = \mathbf{P}^a\mathbf{H}^{\mathrm{T}}\mathbf{R}^{-1} \approx \frac{1}{K-1}\mathbf{X}^a\mathbf{Y}^{a\mathrm{T}}\mathbf{R}^{-1}$$

$\mathbf{Y}^a$: analysis ensemble in observation space, $\mathbf{X}^f_{t|0}$: *t*-hr ensemble forecast
C: Error norm; globally-averaged moist total energy (MTE) [J/kg]



t-hr EFSO (after Langer et al. 2012) at 00 hr.

- ✓ EFSO diagnosis has been implemented and ALERA2 can routinely output 6-hr EFSO values.
- ✓ Sum of EFSO values in ALERA2 can estimate the actual error reduction.



Flow chart of the DA cycle (at *t*=0 and *t*=6) in ALERA2.

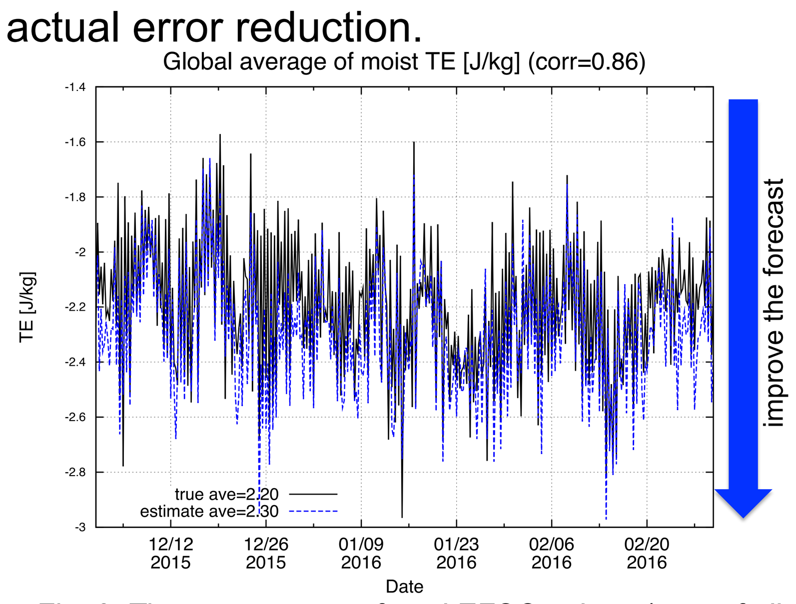
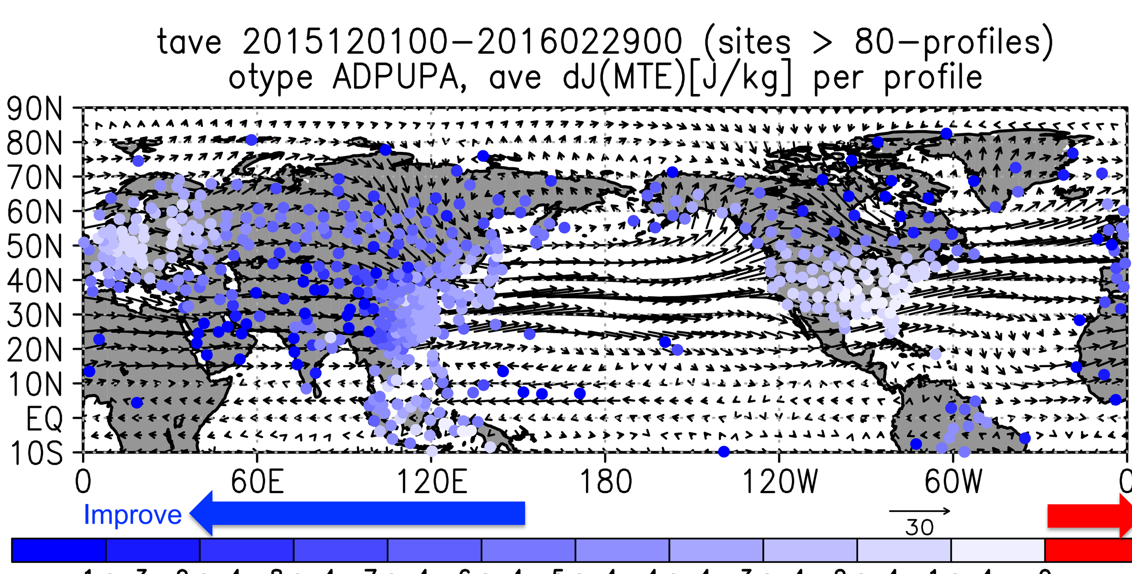


Fig. 3: Time sequences of total EFSO values (sum of all observations, blue) [J/kg] and the actual error reduction (12-hr forecast minus first guess, black) during the DJF.

EFSO-value distributions for routine radiosonde observations



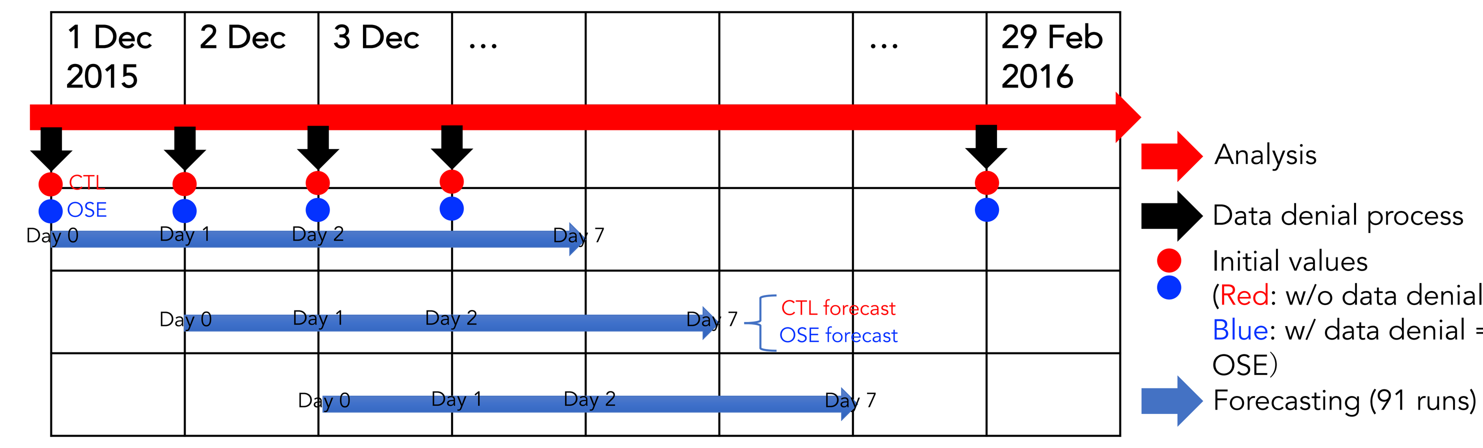
- ✓ EFSO values tend to be greater (more negative) where the radiosonde observation density is lower and at more upstream regions of the westerlies (flow-dependent).

Fig.4: DJF-averaged EFSO values [J/kg] per cycle for radiosonde observations and vertically-averaged wind field [m s^{-1}].

2. Data denial experiments and EFSO diagnosis

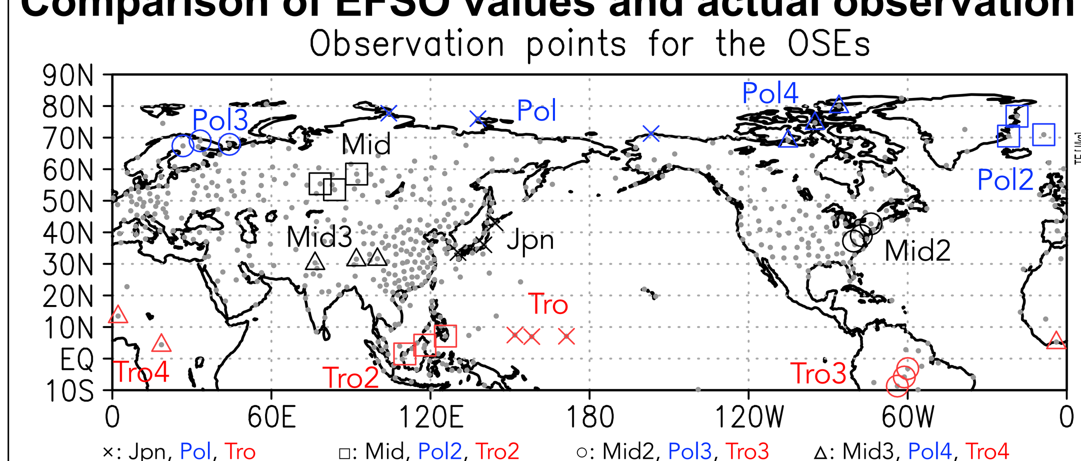
Experimental designs

- ✓ Comparison of the EFSO values and actual impacts of specific radiosondes through OSEs.
- ✓ How useful is the 6-hr EFSO diagnosis to estimate the impacts on weekly (7-day) forecasts?



- 12 data denial experiments consist of 4 sets of 3 radiosonde stations in midlatitudes, the Arctic, and tropics (3 latitudinal regions).
- The data denial is not repeated (once for 1 forecast experiment).
- 91 times (1 Dec 2015–29 Feb 2016) of 7-day forecast experiments for CTL (ALERA2) and OSE initial values.

Comparison of EFSO values and actual observation impacts



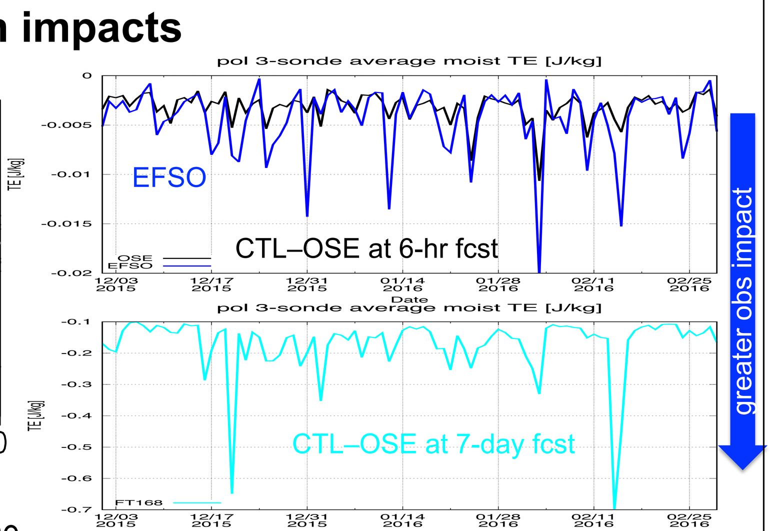
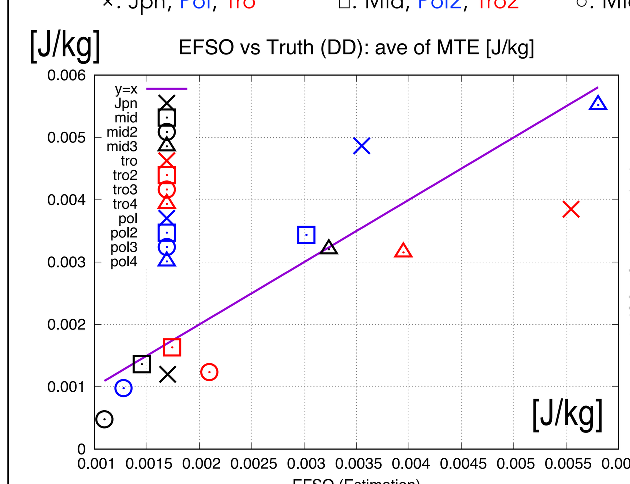


Fig. 5: EFSO values and the observation impacts (CTL–OSE) for the Pol experiment forecast from 1 Dec 2015–29 Feb 2016.



← Fig. 6: Scatter diagram of the DJF (91-times) averaged EFSO values (X-axis) and the observation impacts (Y).

- Observation impacts are defined by difference between CTL and OSEs at a forecast time normalized by MTE [J/kg].
- ✓ EFSO can quantitatively estimate the actual observation impacts obtained in the OSEs.
- ✓ Both time averages and daily variations of the obs impacts should be estimated.

Is 6-hr EFSO diagnosis useful to longer weather forecast?

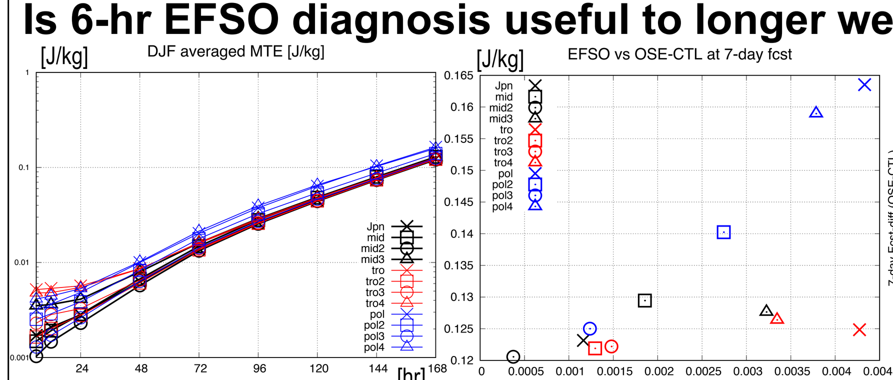


Fig. 7: (Left) time sequences of the observation impacts from 6-hr to 7-day forecast times [hr]. (Right) same as Fig. 6 but for the observation impacts at 7-day forecast time (Y-axis).

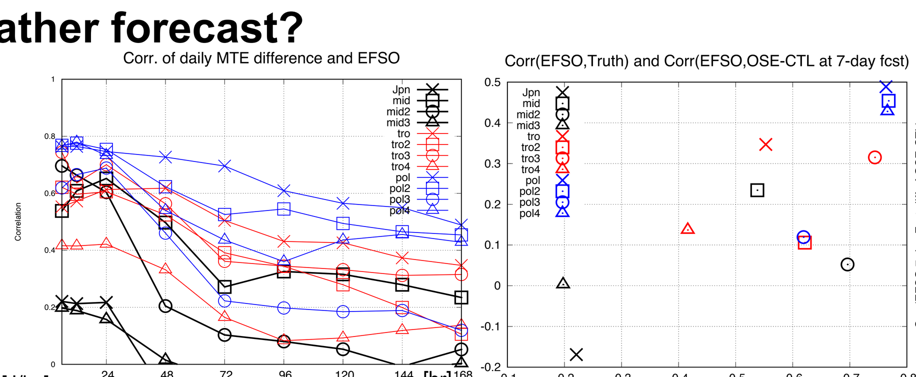
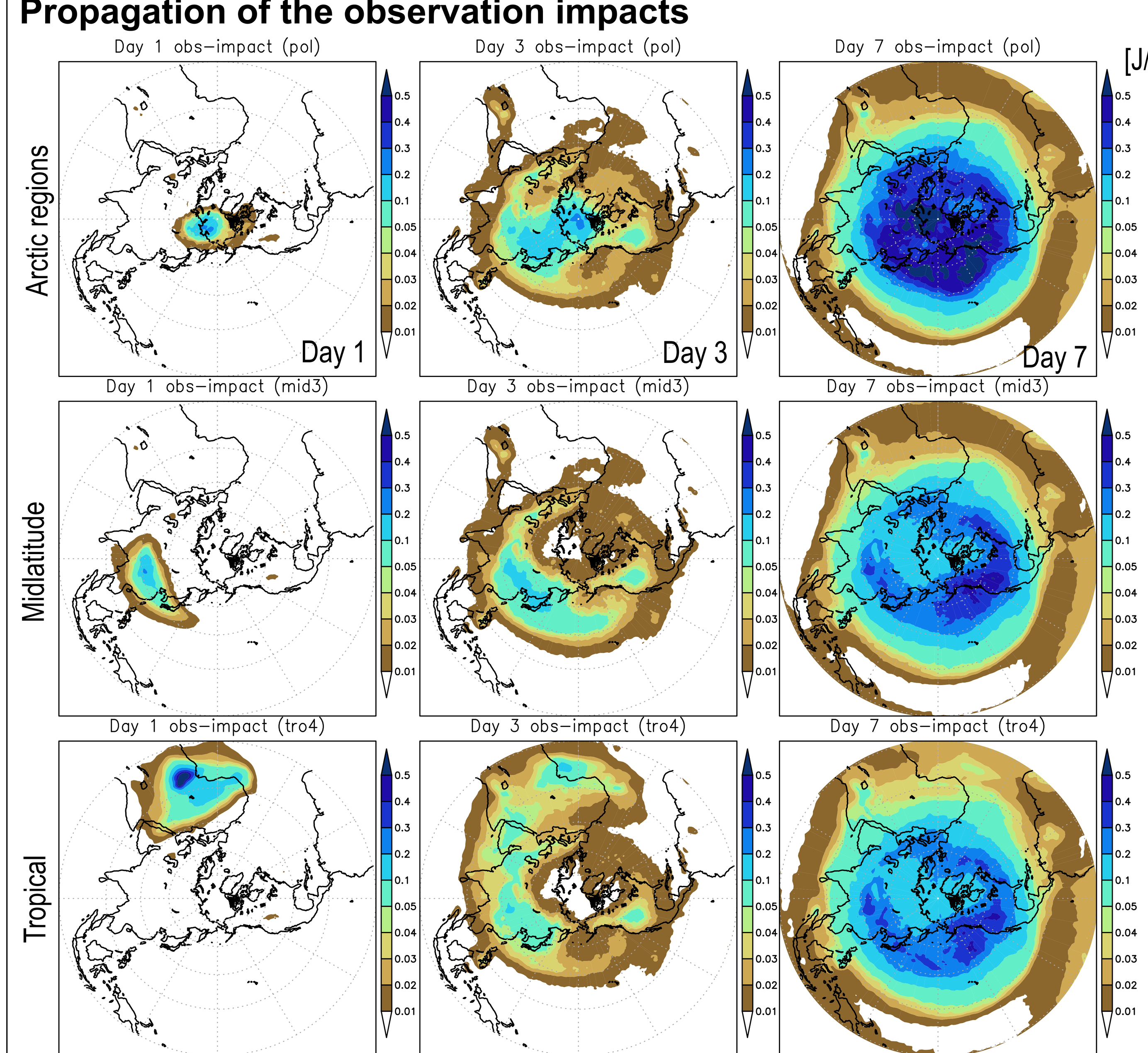


Fig. 8: (Left) time sequences of correlations between the 6-hr EFSO values and the obs impacts from 6-hr to 7-day forecast times. (Right) scatter diagram of the correlations of the EFSO values with the obs impacts at the 6-hr (X) and 7-day (Y) forecast.

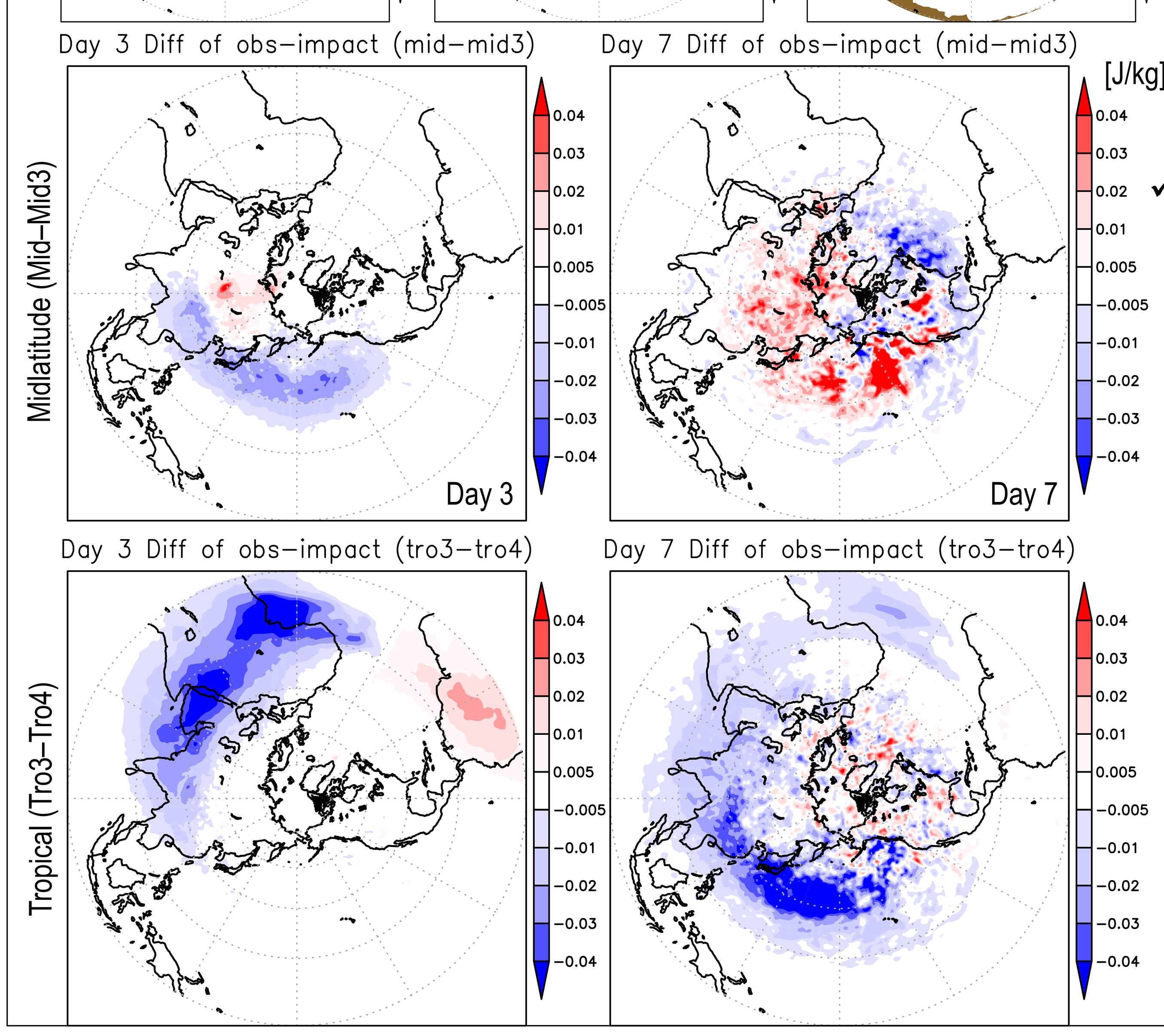
- ✓ Initial obs impacts tend to retain till the 1–2 day forecast period.
- ✓ Greater initial impacts of the Arctic observations tend to more amplify in the latter forecast period in the ALERA2 forecast system.

Propagation of the observation impacts



- ✓ Observation impact from the Arctic observation (Pol) propagates and accumulates near the Arctic Ocean.
- ✓ Observation impacts in the storm-track regions amplify in the latter forecast period irrespective of the observation points.

Fig. 9: Horizontal maps of the observation impacts (difference of CTL–OSE) at 1-day, 3-day, and 7-day forecast times. 3 OSEs of the Pol (×, upper), Mid3 (△, middle), and Tro4 (△, bottom) experiments.



- ✓ Observation impacts of which daily variations were more highly correlated with the EFSO values (Fig. 8) tend to accumulate and amplify more where the observing density is relatively low such as the Arctic Ocean.

Fig. 10: Same as Fig.9 but for differences of the observation impacts between 2 experiments at 3-day and 7-day forecast times. (Upper) the impact of the Mid (□) minus the Mid2 (△), (Bottom) the Tro3 (○) minus the Tro4 (△) experiments.