

Referee #1 (Alan Geer) (Referee's comments in black, our responses in red)

This is a well-written and interesting article that makes a useful contribution to our understanding of wind extraction in 4D-Var. The analytic solutions for the 1-D model form an important part of the paper and help to illustrate the nature of the wind extraction problem. However, the article does need to be careful when drawing conclusions from the 1-D examples. A few suggestions are given below, but it is necessary to remember that the 1-D examples are illustrative, and to be cautious when generalising from them. Otherwise, the article is largely ready for final publication.

This is an excellent point. In the revision, we will be more careful regarding conclusions from the 1-D examples. See responses to points 1 and 3 below for more specifics.

Comments

1 - The conclusions drawn from the single-observation case in section 2.3, particularly from Fig.2, may be overly pessimistic. On P.32997, L.17 it is stated that increased measurement errors lead to "an increased probability that the analyzed wind is worse than the background wind". However, even in the worst case in Fig. 2 (background gradient = 0.2), if we were to take an ensemble of observations and an ensemble of analyses, many more of the analyses would benefit from improved winds than would suffer from degraded winds. Even if on some occasions the wind fields become slightly worse, the assimilation of tracer observations will on average improve the wind fields. Hence even in this case there is benefit to be gained from assimilating the tracer data.

This is a very good point, which we will highlight in the revision. It is true that although in this one-observation case, the winds may become worse in certain circumstances, if we were to take an ensemble of observations with random error σ_{ob} to produce an ensemble of analyses, more of the analyses would benefit from the tracer assimilation. So in a statistical sense, the overall influence of the tracer assimilation is positive, even if in certain cases the winds are degraded, as long as σ_{ob} is specified consistent with the actual observation errors. See also the response to point 3 below.

The really important themes are the usual themes of data assimilation: (a) observation and background errors need to be correctly specified, and if that is true, even the noisiest observation can theoretically provide some benefit; (b) however, any uncorrected systematic differences between model and observations can wreak havoc.

2 - P.32998, L.20. "analyzed wind error reduces by 50% to 0.11". Is that not 0.09, rather than 0.11?

Yes, you are correct here. We will change this to 0.09.

3 - P.32999, L.12. "assimilation of tracer observations has the potential to degrade the winds. A careful tuning of the background error covariances will be required to minimise this problem". Again I would suggest a slightly different interpretation. If the error covariances are correctly specified, the winds should not degrade in a statistical sense. And if the problem is a systematic error, then the ideal solution is bias correction, not error tuning. Of course there is plenty of error tuning done in the real world to deal with issues that are really bias problems!

These are important points. If the background error covariances are correctly specified, the winds should not degrade in a statistical sense for an ensemble of assimilations with random observation errors, even if in certain cases the wind does degrade. This is also discussed in point 3 above. Good point about tuning and bias correction. We will avoid using the word "tuning" in the revision (see also points 4 and 6 below).

4 - P.33000 L.7. "avoid spurious wind increments in the presence of noisy or sparse data". See point 1.

This will be reworded accordingly. We will remove "avoid spurious wind increments" and use "correct specification" rather than "tuning" of error standard deviations.

5 - P.33004 L.8-10. It might be worthy of comment that the wind error standard deviations are far too small for the NH, on the evidence of Fig. 4.

We will include a comment that wind error standard deviations are much smaller than the NH background RMS errors.

6 - P.33010 L.2. "correct tuning of the background and observational error characteristics". In a data assimilation system without systematic error, it should be "specification", not "tuning". This point is made a little further down the conclusion on lines 10-11.

We will change "tuning" to "specification" in both places.

7 - Figure 1. Would it be worth showing the true tracer distribution?

Yes, this is a good idea. We will add the true tracer distribution in Figure 1 (see uploaded figure).