Reply to Anonymous Referee #1

Specific comments

1. While generally well-written the paper contains numerous small English language errors which need to be corrected. I have pointed out many (hopefully most) of these below under technical errors.

We apologize for the numerous small English language errors. Some of them are certainly because we are not native English speakers, but we agree that quite many of them would have been avoidable. Many thanks for carefully pointing out the many corrections, all of which we of course incorporated in the revised version.

2. It would be helpful if a few more sentences could be added on the difference between this version of LAGRANTO and previous version(s). Are the differences just those described as the 'enhanced funtionalities' in the abstract or do other differences exist? Would this version of LAGRANTO produce exactly the same trajectory set as the previous version for an example case (given the same starting positions etc.).

Indeed, nothing has been said about a comparison between the previous and the new version in the manuscript. Of course, many tests have been performed during the development of the new version. One of the powerful tests was as follows: forward trajectories are calculated 48 h forward in time (at any time, e.g., from 00 UTC 1 Jan 2014 to 00 UTC 3 Jan 2014) starting on a globally equidistant grid (80 km horizontal spacing) at 500 hPa (79539 trajectories in total). The jumping flag was set to handle crossings of the lower boundary and potential vorticity (PV) was traced along the trajectories. Then, the air parcel positions were compared (as spherical distances in km) between the calculation based on the previous Lagranto version and the new one. The positions of the two trajectory calculations turn out to be exactly the same, with the single exception of one trajectory that starts exactly at the North Pole. Furthermore, the PV values traced along the trajectories do also agree very well, with most differences below 0.001 PVU. In summary, the two versions of Lagranto result in essentially exactly the same forward trajectories. As an additional test, we repeated the procedure outlined above for backward trajectories leading to the same conclusion: both Lagranto versions result in the same output. Of course, this result is not astonishing because the time step and interpolation methods are 1-to-1 taken from the previous Lagranto version.

We could include these test results in the manuscript, but would prefer not to do so in great detail. The test/comparison itself is of course very important to users familiar with the previous version of Lagarnto, but does not add any value for potential new users. Therefore, we only briefly mention in the manuscript that the two calculations agree. More specifically, we entered the following short paragraph at the end of section 3.3:

"Consistency with LAGRANTO 1.0: The new version of LAGRANTO uses the same bilinear interpolation and time-stepping scheme as LAGRANTO 1.0. Therefore, a perfect agreement is expected if the same starting positions and wind fields are used. Indeed, we performed such a comparison for 48-h forward and backward trajectories, started on a global grid at 500 hPa. All of the trajecories, 79539 in total, agreed perfectly in position and differences for variables traced along the trajectories (e.g., PV and TH) remained negligible."

3. Several other trajectory tools are mentioned in the introduction. In the conclusion 3 special features of LAGRANTO compared to other trajectory tools are listed. Can you be more precise as to whether any of the other trajectory tools you've mentioned incorporate any of these special features i.e. if the user required one of these special features is LAGRANTO the only option?

To the best of our knowledge these specific features are unique to Lagranto – or at least they would require additional programming efforts for the user working with another trajectory tool.

Technical corrections

1. Abstract: the second sentence of the abstract covers a whole 11 lines and the use of semicolons doesn't seem quite right. It would be better just to use them to distinguish the list labels i.e. prior to (ii) and (iii) and to use other punctuation (commas or brackets) to separate other items. Alternatively it would improve readability to separate this long sentence into multiple sentences.

The abstract has been rewritten to increase readability. It now reads:

Lagrangian trajectories are widely used in the atmospheric sciences, for instance to identify flow structures in extratropical cyclones (e.g., warm conveyor belts) and long-range transport pathways of moisture and trace substances. Here a new version of the Lagrangian analysis tool LAGRANTO (Wernli and Davies, 1997) is introduced, which offers considerably enhanced functionalities. Trajectory starting positions can be defined easily and flexibly based on different geometrical and/or meteorological conditions; e.g., equidistantly spaced within a prescribed region and on a stack of pressure (or isentropic) levels. After the computation of the trajectories, a versatile selection of trajectories is offered based on single or combined criteria. These criteria are passed to LAGRANTO with a simple command language (e.g., "GT:PV:2" readily translates into a selection of all trajectories with potential vorticity (PV) greater than 2 PVU). Full versions of this new version of LAGRANTO are available for global ECMWF and regional COSMO data, and core functionality is provided for the regional WRF and UM models and the global 20th Century Reanalysis data set. The paper first presents the intuitive application of LAGRANTO for the identification of a warm conveyor belt in the North Atlantic. A further case study then shows how LAGRANTO can be used to quasi-operationally diagnose stratosphere–troposphere exchange events. Whereas these examples rely on the ECMWF version, the COSMO version and input fields with 7 km horizontal resolution serve to resolve the rather complex flow structure associated with orographic blocking due to the Alps, as shown in a third example. A final example illustrates the tool's application in source-receptor analysis studies. The new distribution of LAGRANTO is publicly available and includes auxiliary tools, e.g., to visualize and merge trajectories. A detailed user guide describes all LAGRANTO capabilities.

2. UM should be changed to MetUM throughout the text as this is the standard acronym for this model.

done

3. Abstract L18: 'example' -> 'examples'

done

4. Abstract: I found this difficult to follow in terms of the example cases initially as it isn't immediately obvious that orographic blocking is one of the examples in the paper (which makes the reference to the resolution needed to represent this rather meaningless). A simple change in L19 to '. . .are needed for the next example to adequately. . .' would improve this.

This should be better now with the improved version of the abstract (see reply to comment 1).

5. p1896, L1: 'application' -> 'applications'

done

6. p1896, L25: change to 'LAGRANTO was first used. . .'

done

7. p1897, L4: 'helped analyzing' -> 'helped analyze'

done

8. p1897, L16: I'd remove the comma after 'themes'

done

9. p1998, L2 and elsewhere: The colon is not usually used in times in Met. papers (i.e. 1200 UTC rather than 12:00 UTC) so I suggest changing this unless the convention is different for this journal.

done

10. p1898, L14: 'available in netCDF..' rather than 'available on netCDF..'

done

11. p1898, L26: Strictly, the suffix .eqd tells LAGRANTO that the starting positions should be equidistantly distributed within the box with a spacing of 80km 'in this example' (rather than generally).

We now mention that it only applies to this example

12. 1898, L28: change to '. . .equidistant pressure levels. . .'

done

13. p1899, L18: you say that the input files could in principle be available every minute, have you tested that this works?

Indeed members of our group are calculating trajectories based on input files available at a time interval as short as a few minutes. Actually an initial test first produced several problems, of course! But after correcting some errors in the shell scripts, LAGRANTO ran with these input files. The major step was to get a time interval shorter than 1 h. In the current version of LAGRANTO, the time handling should work down to 1 min.

14. p1900, L2: I don't understand the relevance of the sentence starting 'Note. . .'. What do you mean by 'the entries are not separated by an empty line'? What are the 'entries' in this case?

We decided to remove these two sentences from the manuscript. Basically, the point was rather technical: If you create a start file, it will also be a trajectory file, but a strange one if you use format 1. It only contains time, longitude, latitude and pressure for each starting position, followed by an empty line separating the first trajectory (starting position) from the next one. If format 2 is used instead, no extra empty line will be written between all the starting position, and the file will hence be more compact. The reviewer is perfectly right that the explanation in the submitted manuscript is not clear enough; on the other hand, a more thorough explanation would need too much text given the minor importance of this little item.

15. p1900, L6 and in lots of other places: The verb 'allow' is used incorrectly throughout this article. For example here instead of 'which allows to trace meteorological fields' you should use 'which allows one to trace meteorological fields' or, probably better, 'allows meteorological fields to be traced. . .'

Many thanks for hinting to this language problem. Searching for 'allow' in the text, indeed it turns out that we use it rather often. We have corrected all instances, if possible with the better version mentioned by the reviewer.

16. p1901, L11: change to 'A well-established WCB can be. . .'

done

17. p1901, L12: change to 'near the surface'

done

18. p1902, 13: 'ECMWF is given' ?

done

19. p1902, L20: It took me a while to work out that (i) referred back to 'ECMWF hybrid sigma-p level type' – perhaps better to say this explicitly.

done

20. p1905, L17: 'fix' -> 'fixed'

done

21. p1905, L18: change to 'proceed on its course'

done

22. p1906, L16: spelling of 'calculation' is incorrect.

done

23. p1906, L24: This should be 'parcels' position' since the position belongs to the parcels.

done

24. p1906, L25: change to 'surroundings'

done

25. p1907, L12: 'being part in both sets' -> 'that are part of both sets'

done

26. p1908, L15: 'a field' -> 'this field' since you are referring to field RTOT in this example.
done

27. p1908, L15: 'it's. . .' 'its'

done

28. p1910, L10: Why can the command 'ALL' only be applied with the label field of 'select'? Table 2 lists examples without the label field.

'ALL' can be applied at two places of a selection criterion. If the general structure is {command:field:parameters:time}, then the first usage of 'ALL' is in the time specification (as in Table 2). There it means that all times listed before are used for the evaluation. On the other hand, if 'ALL' comes right in the beginning, i.e., as a command, then it has a completely different meaning. Here it only applies to the label feature of select and means that labels must be set simultaneously. An option would be to more clearly distinguish between the comamnd and time specification, for instance by using a different name for the commands (e.g., ANYLABEL or ALLLABEL). At the moment we have not included this change into the text because 'ALL' and 'ANY' as commands are shorter.

29. p1912, L21: Don't you need to have at least 3 timesteps to ensure that a criterion applies for a minimum of 12 h (i.e. timesteps at 0, 6 and 12 h)?

The reviewer is correct. Strictly, a criterion could become valid, e.g., at time 6 h and remains so until time 12 h, after which the criterion might no longer be valid. In LAGRANTO, two label would be set because the criterion is fulfilled at exactly these two time steps, but the overall time spand when the criterion applies is only 6 h, We replaced 12 h with 6 h.

30. p1912: In the code 'GT:LABEL(NONZERO):2:ALL' how does LAGRANTO know which label is being tested given multiple labels could be defined?

This is indeed not clear. At the moment LAGRANTO does not allow the label to be specified for the comparison. If this turns out to be too restricting, a more refined command will be included in a future extension of LAGRANTO.

31. p1912, L23: 'loose' -> 'lose'

done

32. p1913, L 7: 'ist' -> 'is'

done

33. p1913, L14: change to 'which has been'

done

34. p1916, L2: change to 'was chosen to be larger. . .'

done

35. p1916, L9: change to '. . .vertical coordinates. It is one of the main features of startf. . .'

done

36. p1917, L22: need to define PBL here (currently not defined until p1921).

Replaced with 'boundary layer height'

37. p1918, L10: 'very' -> 'many'

'very' is removed

38. p1919, L20: change to 'help predict..'

done

39. p1921, L12: DPBL = P – PBL, thus if a trajectory has had contact with the boundary layer its pressure must have exceeded that of the PBL and so I think DPBL should be positive (rather than negative as stated).

Thansks! Yes, DPBL becomes positive at contact with the PBL

40. p1923, L4: 'version' -> 'versions'

done

41. p1923, L14: what is meant by 'geographic coordinates'? For the MetUM at least the non-rotated coordinates are normally referred to as equatorial coordinates.

We replaced 'geographic' with 'equatorial' throughout the manuscript.

42. p1923, L25: 'list' -> 'lists', also consider using a comma after 'file'

done

43. p1925, L26: How can you partly need python as a software tool? Do you mean that you need python for some bits of LAGRANTO but other bits work without it?

Exactly! We changed the sentence to make it more clearly: "In addition to Fortran, several other software tools are needed, in particular Unix csh and Perl. Furthermore, for the visualization tool (see section 5.3) Python is required."

44. p1926, L6: 'since almost 20 years' -> 'for almost 20 years'

done

45. table 1: the last sentence in the caption doesn't make sense and has a spelling error. This sentence could be changed to match the equivalent sentence in the caption of table 2.

done

46. table 2: The use of bold is not consistent here e.g. the first example is for PV greater than 2PVU at any time and the second for PV greater than 2 at all times and yet different bits of the criterion are written in bold in the first column for these examples. I suggest removing the selective use of bold font in this table.

Done; we follow the reviewers suggestion and do not use highlighting with bold font in this table

47. fig 2 caption: 'allows studying of' -> 'allows study of'

done

48. fig 3: why is there a colon after the equals sign in the figure? Also, the use of superscripts * and ** for the different iterations of the forward steps is inconsistent with the text where subscripts (1) and (2) are used.

We have redrawn Fig. 3 and it should now be consistent with the text.

49. fig 4: 'starting position' -> 'starting positions' in caption

done

50. fig 5: should strictly note that the orography is in 'm' and also note that this field is shown in panel b as well as panel a

done; the unit is now mentioned in the figure caption, for both panels.

51. fig 6:please add units of both pressure and density to the caption.

The units are now added to the caption. To clarify the meaning of the density, we added the following sentence to the caption: "In total 1460 backward trajectories are included and then the 6-hourly trajectory positions are gridded onto a 1° x 1° latitude-longitude grid. The values correspond to the total counts per grid cells ."

Reply to Executive editor of GMD D. Lunt

"– The paper must be accompanied by the code, or means of accessing the code, for the purpose of peer-review. If the code is normally distributed in a way which could compromise the anonymity of the referees, then the code must be made available to the editor. The referee/editor is not required to review the code in any way, but they may do so if they so wish. "

The code can be downloaded from the SVN repository mentioned in section.5.4. We renamed the section according to the editor's suggestion and furthermore now provide a more comprehensive web page with several resources related to LAGRANTO (see answer to following concern).

"– All papers must include a section at the end of the paper entitled "Code availability". In this section, instructions for obtaining the code (e.g. from a supplement, or from a website) should be included; alternatively, contact information should be given where the code can be obtained on request, or the reasons why the code is not available should be clearly stated. "

Many thanks for mentioning these important points. Actually, section 5.4 in the manuscript handles this aspect. There it is written: "LAGRANTO is disseminated over an SVN repository (www.lagranto.ethz.ch), where the different versions are available as distinct releases. We, of course, follow the executive editor's remark and renamed section 5.4 into "Code availability". Furthermore, we decided to provide a more general public "front-end" to Lagranto. A website <http://www.iac.ethz.ch/staff/sprenger/lagranto/> now provides several resources: (i) a license; (ii) a tutorial; (iii) the complete reference guide; (iv) a list of selected articles using Lagranto; and (v) a link to the actual SVN repository from where the full Lagranto code, including documentation and installation scripts, can be downloaded. This approach allows a future version of the website to provide additional resources, e.g., we plan to make available a web-based interface to Lagranto in the near future. Furthermore, we decided to make the tutorial and reference guide to Lagranto accessible from this website, and not as supplementary material of the manuscript. The main advantage of course is that future improvements in the documentation will be readily available, which would not be the case with a static supplementary resource.

The following sentence was added at the beginning of subsection 5.4: "LAGRANTO source code and documentation can be downloaded from URL <www.lagranto.ethz.ch>, where the different versions (ECMWF, MetUM, COSMO, WRF) are available as distinct releases."

Reply To Anonymous Referee #2

Specific comments:

- It is noted that American spelling is being used throughout the manuscript (e.g., 'center', 'color', 'favored').

- While generally well structured and clearly written, the abstract is perhaps rather technical in one or two places, e.g. referring to details of analysis commands such as "GT:PV:2". The extended sentence in the first paragraph should also be split to improve readability.

We have rewritten the abstract to improve readability (see also reply to comment 1 from referee 1). However, we kept some technical aspects to indicate some flavor of "how Lagranto works".

- In the introductory discussion around eqn(1), the text suggests that all trajectory models operate in a pressure vertical coordinate, but this is not necessarily the case (height based coordinates might also be used). Suggestion to either make the text less specific here (e.g. remove the word 'pressure' on l.13) or to add a qualifier that LAGRANTO adopts a pressure-based formulation for x and u.

We follow the suggestion and remove 'pressure' on L13. Indeed, LAGRANTO itself relies on different vertical coordinates: In the ECMWF version pressure is used as vertical coordinate for the trajectories, in the COSMO version on the other hand it is height (in m). However, at this place of the manuscript we don't want to go into details and only show the basic principle of trajectory calculations, irrespective of the subtleties of the underlying coordinate systems.

- I read the last sentence of the same paragraph (l. 19 – 20) to imply that LAGRANTO is the only trajectory tool of those listed that has the ability to select trajectories based on objective criteria. If this is not correct, the phrase "in contrast" should be removed from that sentence.

To the best of our knowledge, Lagranto is the only trajectory tool where the iterative selection with objective criteria is a central element of the tool itself. Of course with other tools, it is also possible to do this as part of the post-processing with self-written code, but not as an integral part of the tool itself. We therefore did not change our formulation.

- On page 1902, l.15 states that OMEGA is expected in hPa/s (but it is more usual for OMEGA to be in units of Pa/s in NWP model outputs?)

Indeed, we have the vertical wind in Pa/s on our netCDF file. Hence, the 'default unit' expected by LAGRANTO is Pa/s. However, LAGRANTO checks for the unit of the vertical wind and introduces, if needed, a scaling factor. We now explicitly mention this in the text: " If the unit of the vertical wind is in hPa/s instead of Pa/s, a scaling factor of 100 is automatically applied."

- The use of arrow notation for vectors in Figure 3 makes the schematic look rather cluttered. Perhaps just use bold font instead (as is done in the figure caption).

We have redrawn Fig. 3 and now use bold font vectors.

Technical corrections:

- 1898 / l.3 Consistency in use of ∘ symbol when referring to geographical coordinates, e.g.,30∘ N to 80∘ N (and similarly elsewhere in the paper, e.g., on p.1911).

done

- 1901 / l.13 "northward" (i.e., missing 'h')

done

- 1904 / l.6 "only makes" (i.e., reverse order)

done

- 1905 / l.23 "... is anyway critical" (do you mean "not critical"?)

done; we adjusted the text to 'not critical' as proposed. The wording is indeed a little 'ambiguous': If you consider the air flow in the PBL to be rather turbulent and hence kinematic trajectories to be imprecise anyway, you can argue that **the type of solution** we apply to be **not critical** because the validity of trajectories must be taken with care. Or you argue that the **validity of trajectories** cannot be trusted in the PBL and therefore trajectories in this realm to be **critical.**... Anyway, we now adopted the first interpretation and argue that the type of correction is not really critical.

- 1906 / l.13 First entry should be T:-100 km (i.e. '-' not '+')

done

- 1913 / l.15 "which has been used for more than a decade"

done

- 1916 / l.9 "versatility"

done

- 1916 / l.16 Figure 5a shows the trajectory blocking. Could also add correct reference to Figure 5b in discussion on the following page.

done

- 1919 / l.20 "The forecast trajectories help predict ... or originate from ..."

done

- 1923 / l.14 "trajectory" (i.e. missing 'r')

done

- 1923 / l. 21 "have already been mentioned"

done

- 1924 / l. 4 "losing"

done

- 1925 / l. 26 Use of the phrase "partly Python"? The authors could be slightly more specific here, e.g., on the version of Python and/or any required libraries.

We have removed 'partly' from the text. It was misleading! With respect to the Python version (2.7.5) and the libraries needed (numpy, matplotlib) we would prefer not to mention these pieces of information in the text because they are rather standard Python packages. However, we agree with the reviewer that it can be important for the installation to have some very specific comments. Therefore, we intend to add a FAQ part on the new LAGRANTO web page (www.lagranto.ethz.ch). There, a section could deal with installation issues, e.g., with specific Python libraries and versions needed.

- 1926 / l. 3 "described" (i.e. missing 's')

done

- 1926 / l.6 "since" should be "for"

- 1927 / l.1 "trias" should be "triad"

- Table 2 caption: third entry in table should be "maximum" (typo).

- Figure 6 caption: "panles" should be "panels", and "1500 m" should be "3000 m"

Fig.6 is now removed from the manuscript; one of the two panels is included in the new Fig. 7.

Reply to Anonymous Referee #3

General comments

As far as I can tell the trajectory model itself has not changed, so this article does not describe development of a model, but of a new user interface to an existing model. While there are novel aspects in the functionality of the tool, the article seemed much too long for describing them. It reads more like a mix of review and detailed user guide, rather than an exposition of new scientific development. I recommend a major revision to trim down to a more concise article focussing on the new capabilities and science opportunities offered by the new front end to LAGRANTO, and moving the syntax and instructions to a system user guide, which perhaps could be linked to in supplementary material. For example, Section 3.4 has some clever ideas but the paragraphs are full of script-based commands that interrupt the flow of the discussion and make the article difficult to read. I believe that the command language would be better described in systematic user guide documentation, rather than within text discussion.

Lagranto, as expressed by the last two letters of the acronym, has always been designed as a tool, user-friendly and versatile, in which the "core model", i.e., the actual computation of the trajectories, is only a relatively minor part. This paper clearly reflects this "tool character" by describing in some detail how the user can work with Lagranto and use its functionalities to do innovative research. We think, supported by the feedback of the other referees, that GMD is a journal that also allows the description of tools, i.e., of technical achievements beyond the core model development. We therefore decided to shorten the paper only slightly (some paragraphs that read more like a user guide have been omitted). We also acknowledge that section 3.4 is rather technical, but this section in particular reflects very nicely the concept and rationale of Lagranto.

In the introduction paragraph to section 3.4 we removed the discussion of the different output options (boolean list and list of trajectory numbers). We think that its description takes too much space given the extra value added. Hence, it makes the technical section 3.4 a little shorter. Of course, the remainder of section 3.4 is still rather extensive. On the other hand, we regard LAGRANTO's powerful selection criteria as a particularly valuable feature. It allows many sensitivity experiments to be performed easily, without making any changes to, e.g., Fortran codes. In this sense, in our view it's worthwhile to provide a glimpse at the main selection features of LAGRANTO. The benefit becomes even more apparent, if the full reference guide for the select command is considered (see supplementary material at initial submission, or the web resource in the revised version). Indeed, it's lengthy and very technical style can make it a little intimidating, and a concise summary of the key features, section 3.4 of the manuscript, makes it more accessible.

In section 4.2 we leave out the reference to the trajectory quickview tool (L543-547). This implies that Figure 6 in the original manuscript is removed, and only one of the two panels is later shown in section 5.3 of the revised manuscript. Of course, the text of section 5.3 is acorrdingly adapted. The reviewer is perfelctly right that this is rather technical and can reasonably be omitted. Furthermore, we now think that it's also too technical to list the first few lines of the spherical polygon file (L587-594 in the original manuscript). We remove this part, hence further shortening the section on orographic flows. All the other parts we would like to keep in the section, because they discuss different and important aspects of LAGRANTO's capabilities.

We also decided to remove table 3 which lists some of LAGRANTOs' additional tools. Most of the tools are mentioned already in the text (section 5.2) and, therefore, there is no need to list them in a separate table.

Finally, we decided to shorten also section 4.4. Here we introduced the simple trajectory calculation tool 'tracal' which allows to perform simple arithmetic operations on the trajectory files. The tool is still mentioned in Table 3 and of course some examples are given in the detailed reference guide.

Specific comments

1) l.10: Not all these models solve the trajectory equation (1) iteratively. They all solve it numerically and perhaps with sub-steps as in Runge-Kutta schemes, but these are not iterative.

We have replaced 'iteratively' with 'numerically'. Of course, there are many numerical schemes which are not iterative, e.g., the Runge-Kutta scheme. We are aware of this and, actually, the wording was unfortunate. With 'iteratively' we did not mean the details of the numerical scheme itself, but the basic 'nature' of a trajcetory calculation. It starts with a starting position,

then proceeds to a new position, and continues to do so in the course of the calculation. In this sense, we understood the term 'iteratively, but avoid this confusion now by using 'numerically' instead.

2) Eqn(1): Important to note that u(x,t) since if the wind field were steady (time-independent) then the trajectories could be integrable using a streamline method.

Thank you, this is a very important point, which we also considered when redrawing the schematic Fig. 3.

3) l.13: It is also not true that these trajectory models all use data in pressure coordinates and integrate vertical position using omega. Some use alternative vertical velocities depending upon the input data level type.

This point was also commented by another reviewer. We remove the explicit reference to 'pressure' in the revised manuscript. This should make clear that at this place of the manuscript we don't want to discuss all the technical details of the trajectory calculation, but only its basic 'nature'.

4) In Section 3.1 it is mentioned that different vertical coordinates can be used within LAGRANTO including hybrid-pressure and isentropic coordinates. The second paragraph in Section 3.1 appears to indicate that even if the input data is given on alternative vertical levels that LAGRANTO still integrates (1) in pressure coordinates using omega. Is this true, or does LAGRANTO v2 support the use of different vertical velocities, such as theta-dot (heating) in isentropic coordinates?

At the moment, all trajectory calculation with LAGRANTO v2 are done using pressure as vertical coordinate (or height for the COSMO version). However, we see the value of different vertical velocities and intend to implement this in a future extension of LAGRANTO. Especially heating rates will be of interest if problems in stratospheric dynamics are considered. By providing a web page to LAGRANTO (www.lagranto.ethz.ch) and distributing the code by means of a SVN repository, we hope that further extensions to LAGRANTO can easily be installed by the LAGRANTO user community.

5) l.26: Although it may be true that LAGRANTO v2 offers the user a ready-made tool that can combine selection criteria and enable efficient calculation, it should be noted that the same calculations could be performed (and have been in the literature) using other existing trajectory models, perhaps with less user friendly methods of selecting trajectories.

Of course, one can do very clever trajectory selections with the output of any trajectory model. However, the point is, that the idea of flexibly and iteratively selecting trajectory subsets, based upon physical and/or geometrical criteria, is a central point of the design of the Lagranto tool – and that any user can use this functionality very efficiently without investing in code development. To the best of our knowledge this is a unique feature of our tool.

6) Para 3, Intro: The review here misses the use of trajectory calculations in the stratosphere which was has been extensive since the 1980s. In particular, the long-time integration of trajectories was tested quantitatively using balloons in the MATCH experiment.

The reviewer is correct that our writing did not appropriately reflect the many trajectory applications in the stratosphere. We therefore have changed the sentence as follows and included references to three pioneering trajectory studies in the stratosphere:
"Since the late 1970s – using now wind fields from reanalyses or model simulations – trajectories have been frequently used for investigating different types of atmospheric flow phenomena including extratropical cyclones (e.g., Whitaker et al., 1988; Kuo et al., 1992), orographic flows (e.g., Buzzi and Tibaldi, 1978; Steinacker, 1984), stratosphere–troposphere exchange (e.g., Buzzi et al., 1984; Vaughan et al., 1994; Newman and Schoeberl, 1995), and transport and mixing in the stratosphere (e.g., Austin and Tuck, 1985; Schoeberl et al., 1992; Bowman, 1993)."

References

- Austin, J. and Tuck, A. F.: The calculation of stratospheric air parcel trajectories using satellite data, Q. J. Roy. Meteor. Soc., 111, 279-307, 1985.
- Bowman, K. P.: Large-scale isentropic mixing properties of the Antarctic polar vortex from analyzed winds, J. Geophys. Res., 98, 23013-23027, 1993.
- Schoeberl, M. R., Lait, L. R., Newman, P. A., and Rosenfield, J. E.: The structure of the polar vortex, J. Geophys. Res., 97, 7859-7882, 1992.

7) l.25: "to identify objectively"

done

8) end section 1: The authors state that "possibilities are further increased due to the novel features of LAGRANTO v2". However, I am not convinced that this is true. LAGRANTO v2 appears to make it easier for new investigators to conduct novel investigations along similar lines to those that have been published, but it seems to me that they could achieve this without the v2 front end if they had the required know how.

See reply to comment 5. For Lagranto, it does not make sense to talk about the v2 model and the v2 front end – Lagranto is a tool with the front end as an essential component. The remark that an experienced user who has the required know how can do without a specific tool is true generally, but, in our opinion does not diminish the value of a tool at all. It is exactly the aim of a tool to make things easier, more flexible and more appealing for a wider group of users.

9) Section 2: The authors have chosen to develop a command line interface to LAGRANTO v2 which could work well with a script approach to designing experiments. However, I imagine that it would be possible instead to develop a widget/button driven user interface with the same functionality. This is the reason why I think the specifics of using the interface need to be in a separate user guide. However, the authors could comment on the rationale for the approach they have taken.

Of course, there are many ways how a user can interact with a trajectory model. The reviewer suggests a widget/button driven user interface, whereas we see more value in a basic command-driven one. Certainly, the first approach offers one key advantage: it's very intuitive and can be run without learning mnemonic LAGRANTO commands. On the other hand, we see also some disadvantages compared to the more basic approach chosen for LAGRANTO:

i) Whereas it would be very convenient to have a graphical user interface for the calculation of single or few trajectory calculations, it becomes increasingly cumbersome if the number of trajectories becomes larger. We have run many trajectory calculations which cover more than 30 years, resulting in millions of trajectory calculations. In our experience it turns out that a command-driven interface can easily be embedded into standard Unix/Linux shell scripts and make the handling of these huge calculations very stable. In fact, only by embedding LAGRANTO in shell scripts, with its many powerful tools, LAGRANTO could be optimally used.

ii) Of course, one could argue that a suitable graphical interface for extensive calculations, as described in i), could easily be developed, e.g. by asking for starting and ending dates. Indeed, special graphical interfaces to LAGRANTO are currently developed at our institute or are already published. One is used for radisonde analysis, the other for flight planning. In both cases, the developers relied on LAGRANTO as the underlying trajectory model, but designed a graphical user interface that meets specifically their needs. In short, we think that it would be difficult to develop a graphical interface that suits well the requirements of all potential users of LAGRANTO. Therefore, we prefer to keep a command-driven interface, which offers a lot of versatility and can readily be included in more specialized user interfaces. In some sense, our approach is very similar to existing chess playing programs. They also clearly distinguish between a chess playing machine, and a graphical chessboard with the possibility to interact with the machine. In our view, LAGRANTO offers the machine, but it's up to the users to develop more convenient user interfaces, if needed.

iii) LAGRANTO is developed and run on Unix/Linux platform. We follow its basic philosophy in providing many little tools, accessible from a command terminal, to build more powerful tools. A graphical user interface, on the other hand, would come more like a 'monolithic' tool which defies exactly this principle. Furthermore, if we consider current trends in scientific computing, new programing languages (e.g., Python) are becoming more important. It would be relatively easy to integrate LAGRANTO in such a new setting because of its simple user interface.

In summary, we would strongly prefer to keep the command-driven interface of LAGRANTO, based on our personal and on other researchers' experience. In the same line, we think that the specific commands should remain in the manuscript. They provide a flavor of how it is to work with LAGRANTO. If all specific commands are missing or moved into a separate user guide, it would become rather difficult to grasp the essentials of LAGRANTO. To formulate it in still another way: trajectory calculations are actually rather trivial, just interpolation and forward time-stepping; it's the specific interface that makes the tool very useful. In the case of LAGRANTO, it's a command-driven interface.

10) Section 3.1: "vertically de-staggered" is not a standard use of English. Suggest re-wording and explaining a little.

We replaced 'de-staggered' with 'unstaggered', which to our knowledge is often used in the NWP community.

11) Eqns (2)-(4): Although the scheme described here is the same as in LAGRANTO v1, it requires some justification. There are several other alterative numerical methods that would be higher order and therefore more accurate when the wind field is sufficiently smoothly varying. It is similar to the midpoint, or second order Runge-Kutta method. A key point with the basic (first order) forward scheme is that it is unstable even for simple flows such as circling around a steady vortex (trajectories spiral outwards). Is the LAGRANTO scheme stable (like the midpoint scheme)?

Of course, stability is a key issue when dealing with numerical schemes. In the manuscript we only mention the iterative Euler scheme, or Petterssen scheme, without discussing its numerical stability. Since this scheme has been used in the previous version of LAGRANTO (LAGRANTO v1) very extensively, it has been tested for stability during the development of LAGRANTO v1, and because the new version of LAGRANTO is based on exactly the same numerical scheme, we refrained from repeating the stability tests. However, we fully agree with the reviewer that additional tests are very valuable to confirm this absolutely essential aspect.

We set up a little numerical experiment to test the stability of the iterative Euler scheme. Motivated by the systematic approach taken by Seibert (1993), we chose a purely rotational flow. The vortex centre is placed at 0°E, 45°N and the wind speed is assumed to be constant (10 ms^{-1}). Furthermore, the wind is stationary, i.e., it is not evolving in time. This last assumption implies that the air parcel trajectories must be closed circles and any deviation from this clearly indicates a numerically unstable setting. The flow setting is shown in the figure below with wind arrows. Forward trajectories are then started from four starting positions: (0°E, 10°N), (0°E, 20°N), (0°E, 30°N) and (0°E, 40°N) and run 648 hours forward in time. The outermost trajectory (in blue) just completes a full circle and the final position after these 1296 time steps (taken the default 30 min time step in LAGRANTO) coincides/overlaps very well with the initial position of the air parcel (blue dot). In summary, for such a long forward integration (27 days) the accuracy of the trajectory is indeed not limited by numerical issues, but by several other sources of uncertainty related to trajectory calculations, e.g., the chaotic nature of the flow field itself or the unresolved scales of the wind fields.
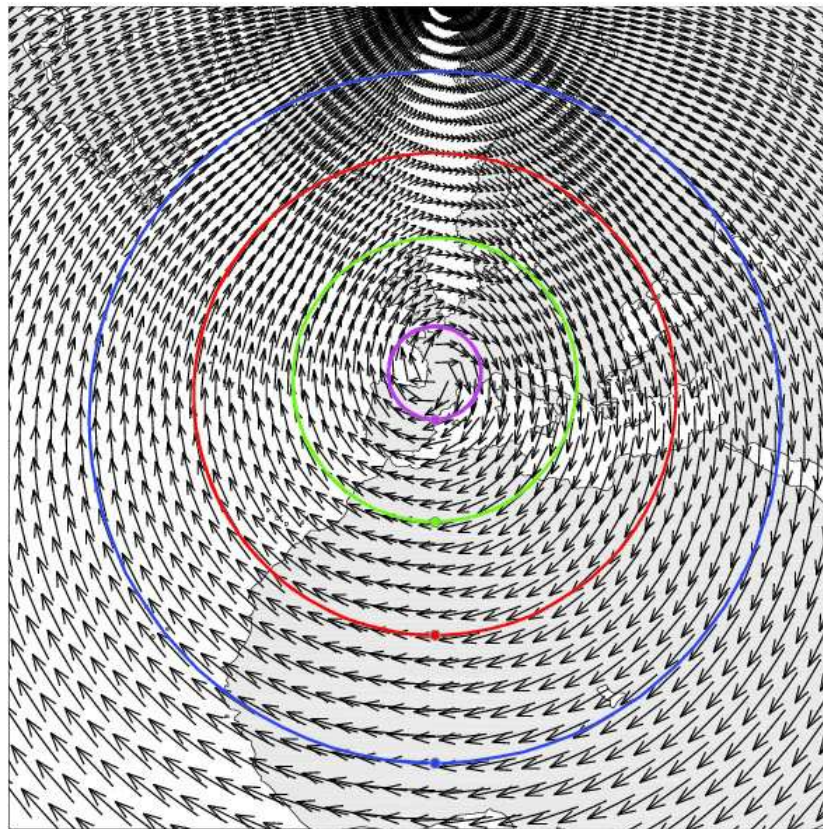
For the other starting positions (red, green, magenta) the outcome is very similar: all circles are nearly perfectly closed. Note that for the innermost trajectory, the constant wind speed of 10 ms^{-1} and the long forward integration time implies that actually 6.5 circles are completed at the end of the test. This can be most easily captured from the following figure, which shows the latitude as a function of the 6-h time intervals. Any instability would become discernible in a change of the

amplitude of the oscillations as time increases.
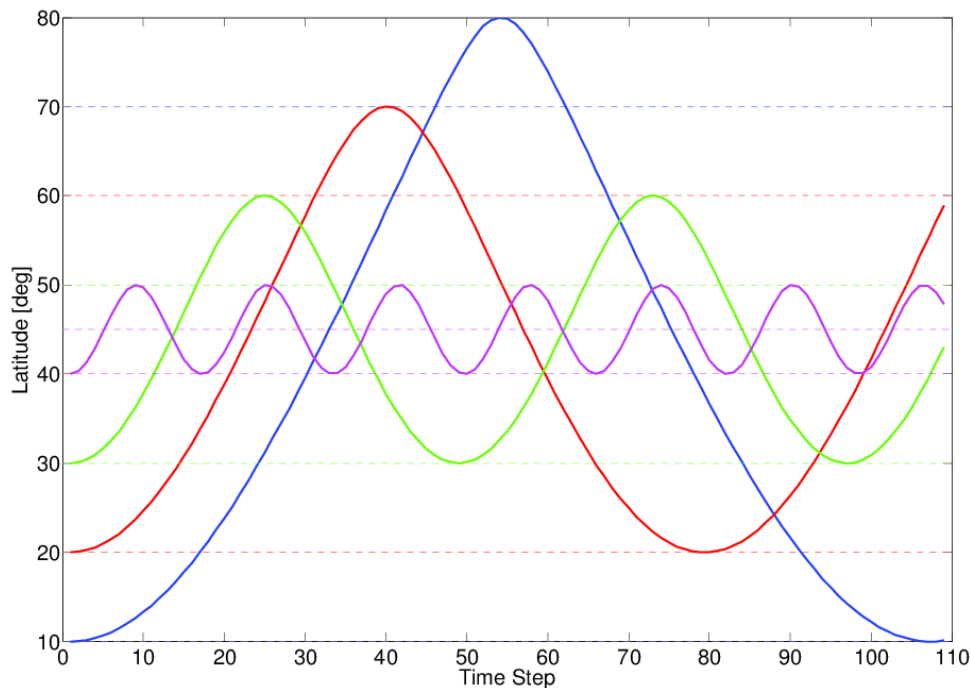
Finally, it is worthwhile to mention that LAGRANTO includes a 2nd order Runge-Kutta scheme, but it is not used in the default setting.

In summary, we can confirm that LAGRANTO v2 is numerically stable and the accuracy of the trajectories are determined not by numerical, but by physical processes (atmospheric chaos, unresolved scales of driving winds). With respect to the manuscript, we think that no detailed discussion of these stability checks must be included. However, we mention shortly that stability checks have been performed and turned out to be successful. We added the following sentences in section 3.3:

"The stability of the numerical scheme was tested in a rotational flow setting (see Seibert, 1993) for 648-h forward trajectories. No hint for any numerical instability could be discerned for these rather long trajectories."

Reference:

Seibert, P. (1993): Convergence and Stability of Numerical Methods for Trajectory Calculations. Journal of Applied Meteorology, Vol. 32, pp. 558-566.

12) Section 3.3, l.15: It does seem a weakness that trajectories can cross below ground. This is avoided by design in some models by using the lower boundary condition on vertical velocity when interpolating velocity to particle locations. It is possible to do this in pressure or hybrid (eta) coordinates.

We fully agree that this is a weakness and during the last years, we made several attempts to solve this problem when using vertical winds in pressure coordinates on model levels.
So far, all our attempts have been unsuccessful, and a detailed discussion of this issue is included in our COSMO online trajectory paper (Miltenberger et al., 2013, section 2.2). We discussed this issue also with John Methven, and in his trajectory code the problem does not occur when using eta-dot as the vertical velocity on half-levels. However, the problem that trajectories go below ground also occurs in his code when using pressure coordinates. We therefore, at the moment, do not see an alternative to the frequently used "solution" of reinserting surface-intersecting trajectories above the ground, and agree with the referee that more attention should be paid to this issue in the future.

13) INPOLYGON: what does a "spherical polygon" mean? It seems like an inappropriate description to me since a sphere has only one curved face.

We agree that the term 'spherical polygon' might not be well known. It refers to "a closed geometric figure on the surface of a sphere which is formed by the arcs of great circles" (see http://mathworld.wolfram.com/SphericalPolygon.html). We changed the footnote in the following way to make the definition more clear: "The INPOLYGON field relies on spherical polygons, i.e., closed geometric figures on the sphere formed by arcs of great circles. For LAGRANTO they are specified as a list of longitude/latitude vertices and a single latitude/longitude point inside the polygon."

14) Section 4.4: For back trajectories it is also necessary to read the input wind records in reverse order as well as rotating the wind vectors by 180deg.

Done; finally we decided to remove the technical details about the calculation of backward trajectories completely. Of course, the reviewer is right in pointing out that the input files also must be read in reverse order. But it's rather straightforward and we therefore skip it altogether.

15) Figure 6 caption: "All panels . . ."

Figure 6 is removed in the revised version of the manuscript, and combined with Figure 8.

Reply to Anonymous Refree #4

- Comments: p.1895: when listing the other dispersion models, it would be good to mention the UK Met Office's NAME model.

Thank you for pointing to the MetOffice's NAME model. If we mention it, we would also have to mention other trajectory dispersion models, e.g., the FLEXPART model. Note that the list of model on P1895 only includes 'trajectory tools' as compared to 'dispersion models'. Of course, the distinction between the two is a little artificial, but we prefer to keep the list of trajectory tools short. Further, note that we discuss very shortly the difference between the two model types in the footnote on p. 1905.

- p.1894 line 18: these examples rely on

done

- p.1901 line 13 Northward

done

- p. 1905 line 18 Proceed ON its course

done

- p.1907 line 12: Present in both sets /being part of both sets

- Figure 6 text: Panels

Figure 6 is removed in the revised manuscript and combined with Figure 8