

Response to reviewers of “The Aerosol Characterization from Polarimeter and Lidar (ACEPOL) airborne field campaign,” Knobelspiesse et al, ESSD-2020-76

<https://doi.org/10.5194/essd-2020-76>

Reviewer #1 (Meloe Kacenenbogen)

This paper is an overview of the ACEPOL airborne field campaign. Its purpose is to document ACEPOL’s initial hypothesis, science objectives, atmospheric conditions, field deployment, airborne and ground-based instruments, and scientific outcomes. It is, for the most part, well structured, clear, and well-written. I consider the necessary revisions minor as they do not involve any extensive data analysis. However, others might consider them major as they are beyond the correction of a few typos. Overview publications of airborne field campaigns are unique and, in my opinion, very useful. I recommend this manuscript for publication only after the following comments and suggestions are addressed.

We thank the reviewer for her thoughtful and through comments. They improve the manuscript and we are grateful for the time she spent reviewing our manuscript. We believe we can accommodate or respond to all comments.

Overall comments.

Data archive and availability should ideally be described in one place instead of many (e.g., in each instrument sections 3.1.1- 3.1.4 and section 3.4).

Section 3.4 (“Data Availability”) and Table 3 (in the same section) are the primary location describing archive location and availability. Additional details in the abstract are a requirement of the ESSD journal format. Archive details in each instrument section are not presented, instead those sections point to section 3.4 for details on this.

Consider adding a table of ACEPOL (and possibly PODEX) related papers (e.g., published, in review, in prep i.e. conferences or technical reports), instruments involved and the science objectives they mainly address.

While this is a good idea, we’re afraid it would become rapidly out of date since research with ACEPOL data is ongoing. Instead, we are looking into creating such a table on the primary archive landing page, which can be updated as new publications are created.

Section 2 (Objectives) should state and describe ACEPOL’s objectives more clearly and describe how ACEPOL has addressed each one of them.

To accomplish this, we added the following two paragraphs to section 2. More details of the achievements for specific objectives follow.

“Target types fell into four broad categories: calibration, geolocation, validation, and targets of opportunity. Calibration targets (1a, 1b, and 1c) were meant to provide spatially uniform observations with which radiometric and polarimetric measurements between multi-angle polarimeters can be compared. A similar intercomparison was performed during the Polarimeter Definition Experiment (PODEX) between the RSP and AirMSPI instruments (Knobelspiesse et al., 2019). Intercomparison can now be performed with those instruments plus AirHARP and SPEX Airborne. Such intercomparisons can confirm measurement uncertainty estimates and identify calibration problems. Different scene types are useful for intercomparison: cloud free ocean observations (1a) provide low reflectance, potentially highly polarized measurements, while land scenes can have high reflectance but moderate to low polarization. Cloud scenes provide high reflectance and low polarization. Intercomparison requires accurate geolocation, so minimizing scene heterogeneity and atmospheric variation is important. Furthermore, scenes with distinct features, such as coastlines, were targeted to provide a geolocation reference (1d). Validation targets are used to test the geophysical products retrieved by the airborne sensors against similar observations on the ground (2a, 2b), by other field campaigns (2c), and by satellites (3a, 3b). Targets of opportunity are intended for algorithm development and represent infrequently observed or difficult scenes. Finally, it should be noted that the target number designation roughly indicates priority. Low numbered targets are of highest priority, and are generally organized such that targets supporting validation or calibration of radiometric quantities have greatest precedence, followed by validation of geophysical products derived from such observations, and then special cases and difficult scenes (targets of opportunity).

Most of the highest priority targets were observed successfully during ACEPOL, although conditions precluded observation of uniform marine stratocumulus cloud decks (target 1c), and most cases of high aerosol loads. The latter was highly unusual for this part of the world, as California’s San Joaquin Valley and the Los Angeles metropolitan area are known for typically high aerosol loads. The solution was to overfly controlled forest fire burns farther afield in Arizona. Attempted coordination with the Coupled Air Sea Processes and EM Ducting Research (CASPER) East (Wang et al, 2018) field campaign was unfortunately not possible because of scheduling difficulty and weather. Serendipitously, one flight overlapped with a flight by the Alpha Jet Atmospheric Experiment (AJAX), which carried a payload of atmospheric gas sensors. High aerosol loads over the ocean (4a) were not observed, but low aerosol load overflights of an AERONET site (2b) on a platform off Long Beach, CA have become the basis for several analysis papers (e.g. Fu et al, 2019, Gao et al, 2020). Another important accomplishment was the successful overflight of Rosamond Dry Lake from multiple headings while a ground based team characterized the spectral reflectance of the lakebed. This was used to

vicariously adjust the AirMSPI calibration, and serves as a reference for other measurements as well.”

Consider explaining more clearly how ACEPOL differs from or complements PODEX.

More detail was added to section 2.1.

Consider describing ACEPOL vicarious calibration in more details and which instruments are concerned

We expanded on this in section 3.3.3

Some figures need further description and analysis, especially the ones showing scientific results such as spectral AOD comparison, reflectance (e.g., Fig. 4, 8, 9) As an illustration, consider showing Aerosol Optical Depths derived from AirMSPI, RSP and SPEX (in addition to AOD from AirHARP on Fig. 4)

Our general philosophy in this manuscript has been to illustrate the types of data comparisons that can be made, and provide the tools for interested members of the community to identify data most appropriate for their needs. In that light, Figures 4, 8, 9 are meant to be illustrative, and scientific results are the domain of cited and future publications. This delineation corresponds to the scope of the ESSD journal, which states: “Any interpretation of data is outside the scope of regular articles.”

Detailed comments

Line 34 (and any other place in the manuscript): It should say HSRL-2 instead of HSRL2.
Corrected, thank you

Line 47: “While existing passive . . . (Mishchenko et al., 2004).” This statement could use more information.

Added the sentence: “In other words, the remote sensing retrieval solutions are often non-unique, and require the use of constraints in the form of, for example, aerosol models, which may or may not represent geophysical reality.”

Line 55: “previous ocean color satellite instruments” could use some examples
Reference to SeaWiFS added

Line 74: CATS needs a reference, possibly McGill et al. [2015] McGill et al., 2015; McGill, M. J., J. E. Yorks, V. S. Scott, A. W. Kupchock, and P. A. Selmer (2015), The Cloud^Å R[˘] Aerosol Transport System (CATS): A technology demonstration on the International Space Station, Proc. SPIE 9612, Lidar Remote Sensing for Environmental Monitoring XV, 96120A, doi:10.1117/12.2190841.

A good suggestion, thank you

Line 87: replace “at” by “the” in “high altitude vantage point of at aircraft.”

Done, thanks

Line 87: consider replacing “perhaps” by “to our knowledge”

We modified this sentence to: “Deployment of an instrument on this aircraft is a close analog for the space environment and observation conditions.”

Line 99: objectives are (i) test new observations systems, (ii) develop new algorithms, or (iii) validate orbital observations. Consider giving a subsection to each of these three objectives and provide more information. For example, current section 2.2. would fall under objective (iii).

We expanded on this considerably as noted above.

Section 2.1 describes how ACEPOL relates to ACE and PODEX. Consider including this in the introduction instead (giving it its own section outside of section 2).

ACE was one of three providers of funding supporting ACEPOL, so we would like to keep this in a separate, sub-level section (2.1 vs 2, when CALIPSO and SRON support is described in 2.2 and 2.3). However, we did add some text to section 2.1 to better describe the relationship between ACEPOL and PODEX, as suggested above.

Line 101: “For that reason, a wide range of observation conditions were desired”. Consider including examples of easy or challenging atmospheric conditions for specific MAPs or Lidars retrievals.

We put in some language that “targets of opportunity”

Line 103: How were targets prioritized?

We put some text in section 2 on this:

Low numbered targets are of highest priority and are generally organized such that targets supporting validation or calibration of radiometric quantities have greatest precedence, followed by validation of geophysical products derived from such observations, and then special cases and difficult scenes (targets of opportunity).

Line 106: If the objectives are as general as “(i) test new observations systems, (ii) develop new algorithms, or (iii) validate orbital observations” (line 99), then BRDF, BPDF and ocean color algo. might still fall under (ii) and (iii)?

Perhaps correct. But we’d like to include this wording to indicate that these less obvious objectives might be achievable, and even by other instruments (we added that note).

Line 121: Consider listing MAPs and lidar(s) during PODEX. Were ACEPOL and PODEX designed to address the same science objectives? Were synergistic algorithm(s) involving MAPs and lidars not possible during PODEX? Why?

Section 2.1 has been reworded such that it now lists the MAPs and Lidars used during ACEPOL (which were RSP, AirMSP, PACS and CPL. PACS didn't work). While there is some overlap between PODEX and ACEPOL objectives, the latter was important because several new instrument (concepts) were available: AirHARP, SPEX Airborne and HSRL-2.

Line 132: Can the authors add any publication, even in preparation, that will use ACEPOL data for a CALIOP/ CATS validation effort?

Thanks, some references for this were added.

Line 133: Does SRON have different objectives than the overarching ones on Line 99 (albeit more specific to SPEX)? Is there a reason to single out SRON in the objective section? Section 2.3 seems redundant with section 5.4 (and possibly 5.5)

Although the technical objectives of ACE and SRON have significant overlap, we need to show that actual funding was supplied by SRON to support ACEPOL flights. SRON's objectives are the development of the SPEX concept, which is participating in PACE, but is under consideration for other missions as well.

Line 137: NASA PACE mission needs a description as soon as introduced (instead of on line 164)

A good point, we added more detail and a description of PACE to section 2.3.

Line 146: Is there no published reference for AirHARP?

AirHARP characteristics are best described in the McBride and Puthukkudy papers, which are cited.

Line 161: HARP CubeSat instrument needs a reference too, possibly Vanderlei et al. [2016]. J. Vanderlei Martins, "HARP: Hyper-Angular Rainbow Polarimeter CubeSat," ESTO Science and Technology Forum, June 14, 2016, URL: https://esto.nasa.gov/forum/estf2016/PRESENTATIONS/Martins_A1P2_ESTF2016.pdf "HARP Hyper-Angular Rainbow Polarimeter," USU/SDL, URL: <http://www.sdl.usu.edu/downloads/harp.pdf> Does it have a scheduled launch date? Consider adding a reference to section 5.2 here.

HARP CubeSat has been launched and is producing data!

Line 163: "will provide global coverage two days," I don't understand this statement. *Missing a crucial 'in'. Given orbit and swath of PACE/HARP2, all points on the globe will be imaged in the course of two days.*

Line 170: AirHARP AOD seems to reach 1 at 440 nm on Fig. 4d. Can you describe this briefly and possibly how it compares to other MAPs?

The large aerosol optical depth in that scene is unsurprising given that this is a forest fire smoke plume at its source. Puthukkudy et. al 2020 has a comparison of HSRL-2 measured AOD with AirHARP retrieved AOD at 532 nm for the same smoke scene. The results show that there is good agreement with HSRL-2 measured AOD with exception of some points near to the smoke source. The spatial resolution mismatch between HSRL-2 and AirHARP measurements are the main reason for this. For the same smoke scene, Fu et. al 2020 also shows that there is a good agreement between the retrieved AOD from SPEX airborne, and RSP with the HSRL-2 measurements.

Line 172: Here “McBride et al., 2019” instead of “McBride et al., 2019 in preparation” on line 158.

This has been updated.

Line 174: consider discussing data availability for AirHARP? In Fu et al., 2020, it says “Note that aerosol retrievals from AirHARP measurements are not included in this paper because the data were not available when performing the analysis presented here”

Currently, most AirHARP data are in the archive. There was an initial delay as calibration techniques were resolved.

Line 184: “see section 5.3” instead of section 6.3

thanks

Line 196: change to Fu et al. [2020] Fu, Guangliang, et al. "Aerosol retrievals from different polarimeters during the ACEPOL campaign using a common retrieval algorithm." (2020).

Updated, thanks. They changed the title from discussion to final version of this paper.

Line 229: consider referring to section 3.4 for data availability and to Fu et al. [2020] (and any other publications I am missing) concerning RSP-ACEPOL specific analysis

Reference added

Line 248: “Fu et al., 2020” Line 279: “Muñ Ller et al., Sawamura et al.” need years. Another good reference for HSRL-2 might be Burton et al. [2018] Burton, S. P., et al. "Calibration of a high spectral resolution lidar using a Michelson interferometer, with data examples from ORACLES." Applied optics 57.21 (2018): 6061-6075.

Thanks, the references were updated as noted and now represent how the HSRL team desires to report citations.

Line 281: correct to “extinction” instead of “depolarization” at 355nm (i.e., 3 beta + 2 alpha and depolarization at 3 wavelengths for HSRL-2 instead of 2 beta + 1 alpha and depolarization at 2 wavelengths for HSRL-1)

Thank you, the text is correct now.

Line 313: consider replacing “inversion products” by aerosol intensive properties (single scattering albedo, size distribution etc.).

Done, thanks

Line 322: should say aerodynamic diameter

Yes, thank you

Line 324: should say “gaseous criteria for . . .”?

Got it, thanks

Line 334: consider describing “ACEPOL vicarious calibration efforts” and which remote sensing instrument this concerns.

More details regarding this were added to that section.

Line 339: consider adding a reference for “Reagan sunphotometer”, possibly Bruegge et al., [1990] that describes this sunphotometer. This paper also references Shaw et al. [1973] Bruegge, Carol J., et al. "In-situ atmospheric water-vapor retrieval in support of AVIRIS validation." Imaging spectroscopy of the terrestrial environment. Vol. 1298. International Society for Optics and Photonics, 1990. Shaw, G.E., Reagan, J. A., and Herman, B. M. (1973), Investigations of atmospheric extinction using direct solar radiation measurements made with a multiple wavelength radiometer, J. Appl. Meteorol. 12:374-380.

More details and references were added.

Line 349: The difference between Reagan and microtops AOD at specific wavelengths (Fig. 8) should be explained in the text

This is described now in the text – there is possibly a pressure error for the Microtops instrument, so the Reagan was used as a reference.

Line 386: correct “Figure 10 Flight tracks for the ACEPOL field campaign.is a graphical illustration of ACEPOL flight tracks.”. Also, “Details on the characteristics of each flight are in Table 4” seems to be a repeat of line 374

Fixed.

Line 388: consider explaining “somewhat unusual conditions”

Added ‘low aerosol’

Line 391: “constrain observations by”: consider specifying which airborne remote sensing instrument (or algorithm) needs to be constrained

Reworded to say “validate retrievals by”

Line 415: “test of retrieval capability”. Consider briefly reporting the results from Fu et al. [2020] or any other relevant publication as an example

While it is probably out of scope to go into too much detail, we added reference to a number of publications here that analyze ACEPOL data

Line 425: consider more specifics on how ACEPOL data are used in the ACCP efforts (e.g., used to constrain canonical cases in theoretical studies or to attribute instrument specific uncertainties or to attribute scores to different candidate satellite architectures in respect to specific science objectives?)

This is an ongoing activity, but as far as we are aware is in it’s preliminary stages. It has not yet been published in the literature.

Line 441: consider adding any studies underway (i.e., studies that use ACEPOL-AirHARP to help HARP CubeSat design and algorithm)

This section was updated

Line 445: MAIA will provide speciated PMs (said on Line 457). This is one step further from aerosol “typing”.

Language updated

Line 454: delete “total and” in “retrieve total and AOD”

thanks

Line 457: “A geostatistical regression modeling framework will be used to transform column aerosol optical and microphysical properties to speciated, near-surface PM concentrations”. Consider possibly adding Kalashnikova et al. [2018] here and any other (more) relevant publication Kalashnikova, O. V., Garay, M. J., Bates, K. H., Kenseth, C. M., Kong, W., Cappa, C. D., et al. (2018). Photopolarimetric sensitivity to black carbon content of wildfire smoke: Results from the 2016 ImPACT-PM field campaign. *Journal of Geophysical Research: Atmospheres*, 123. <https://doi.org/10.1029/2017JD028032>

We added this reference, thank you.

Line 459: consider adding any studies underway (i.e., studies that use ACEPOL-AirMSPI to help MAIA design and algorithm)

As far as we are aware, no such studies are underway, at least in the published literature.

Line 472: Fu et al. [2020]

Thanks

Line 475: is this still happening in May 2020 (under COVID-19)?

The SCARBO campaign is currently scheduled for September, 2020, depending on the COVID-19 situation. Text has been updated to reflect this.

Line 476: MAMAP and NanoCarb need to be introduced and described

More background information and citations are now provided.

Line 478: consider describing how ACEPOL-related airSPEX data will help those upcoming deployments as Section 5 is about “value (of ACEPOL) for future missions”

We added a sentence for this. In addition to previously mentioned work, the data processing system developed for ACEPOL is being used for future field campaigns.

Conclusion: please consider re-stating the ACEPOL objectives and how they were addressed, as well as recapping the value of ACEPOL in future missions (e.g., PACE, MAIA, HARP CubeSat, ACCP)

We added more description of this in the short conclusion.

Figure 4d: “tau” should be “AOD” next to the color bar.
done

Figure 8: What does “Junge” stand for? Also the difference between Reagan and microtops AOD at specific wavelengths should be explained in the text

This was a Junge aerosol model fit to the Microtops data. We updated the text to explain this.

Figure 9: What does “HDRF” stand for?

The Hemispherical-Directional Reflectance Factor. We spelled this out and provided the appropriate reference.

Reviewer #2

General Comments

This paper describes the ACEPOL campaign in order to test six observation instruments and new developed algorithms for accurate measurements of cloud and aerosol optical properties. The flight campaign and the data provided are useful for reducing aerosol-cloud climate forcing uncertainty. I believe this paper is suitable for publication to Earth System Science Data after considering comments as below.

We appreciate your sentiment and comments.

Specific comments 1. The data provided by the ACEPOL campaign are important for this paper, so it's better to describe the specific data types, such as aerosol AOD, or vertical profile of cloud, in Table 3.

Since the focus of ACEPOL is instrument and algorithm development, so called "Level 1" data are in the archive. Level 1 data are calibrated observables, such as radiance or reflectance, polarization, or backscatter. Level 2 data are products of retrieval algorithms and include, for example, aerosol intensive and extensive parameters. These may or may not exist in the database(s) depending on the retrieval algorithm maturity. We made a note of this in the table description.

2. The five instruments and the corresponding data was calibrated except AirMSPI, does this instrument need radiometric calibration?

All instruments were calibrated, albeit with different techniques and facilities. AirMSPI uses a vicarious adjustment to calibration coefficients based upon the ground based observations of the Rosamond Dry Lake.

3. Section "Conclusions" should summarize more information about the data archived, including specific data type, spatial resolution, temporal resolution, etc.

We updated the Conclusions to provide a more detailed description of the objectives of ACEPOL and the aspects of those objectives that were successfully retrieved. The resolutions, spectral character and other aspects of data type are described in Table 1.

Technical corrections

Line 87 The sentence is difficult to be understood: "It is, perhaps, the closest an airborne instrument can get to a space deployment." Please rewrite this sentence.

We modified to: Deployment of an instrument on this aircraft is a close analog for the space environment and observation conditions

Line 146 ". . . designed characterization of" -> "designed for characterization of"

Corrected, thank you

Line 164 “mission due to launch in 2022”->” mission due to be launched in 2022”

Considering the current pandemic, modified to “no earlier than 2022” as it is likely the launch date will slip.

Line 386 Remove “Flight tracks for the ACEPOL field campaign.” from the sentence “Figure 10 Flight tracks for the ACEPOL field campaign.is a graphical illustration of ACEPOL flight tracks.”

Corrected, thank you

Reference Please make the format consistent for all references. For example, some references have DOI link, while some have no DOI.

Ok

Line 826 “angle produce a full pushbroom image”->“angle produces a full pushbroom image”

Fixed, thanks

Figure 4(d) Lacks label for y-axis, i.e. “Latitude”

Done. Thank you.

Reviewer 3

General:

This manuscript documents collection of atmospheric aerosols using 4 polarimeters and 2 lidars onboard ER-2 during ACEPOL. The CPL lidar has a horizontal resolution of about 200m and a vertical resolution of 30m, while the HSRL_2 has a horizontal resolution of 1-2 km, and a vertical resolution of 15m.

The 4 polarimeters onboard ER-2 contains spatial sampling from about 42.9 km, 9 km, 280 m per pixel, to 6-degree cross track. The resolutions range from about 10 m at ground to 1 km. There were 9 ACEPOL flights conducted in October-November 2017. Dates of calibration of ACEPOL data were described in Table 2. There are 9 days with calibration days specified: 10/19, 10/23, 10/25, 10/26, 10/27, 11/01, 11/03, 11/07, 11/09.

Test of data accessibility (see below) indicates that the data is not user friendly. Please refer to the NASA GTE project, which contains lots of flights of data. The GTE data are very easy to use and user friendly.

We appreciate the attention of the reviewer. We presume you're referring to the Global Tropospheric Experiment series of field campaigns from the 1980's and 1990's. The ad hoc style of data archive website used for GTE is quite out of date and we presume difficult to maintain. Indeed, most of the links on that page are broken. NASA data archives and distribution are now managed by the Earth Observing System Data and Information System (EOSDIS) which uses a system of Distributed Active Archive Centers (DAACs). The Atmospheric Science Data Center (ASDC) is one of those DAACs. The format and delivery of ACEPOL data conform to the requirements of the ASDC, and are presented in a consistent manner with other field campaigns.

That said, we believe most the sentiment of user friendliness is a simple misunderstanding. Because of the impermanence of website URL's, we use Digital Object Identifiers (DOI's). If maintained properly, a DOI (using the website doi.org) will always point to the proper URL for a dataset. Use of DOI's is a requirement of this journal.

It appears the reviewer concatenated the URL and DOI's into non-existent URL's. For example, The ASDC archive can be accessed at:

<https://asdc.larc.nasa.gov/project/ACEPOL>

OR by searching DOI.org for:

[10.5067/SUBORBITAL/ACEPOL2017/DATA001](https://doi.org/10.5067/SUBORBITAL/ACEPOL2017/DATA001)

But not at

<https://asdc.larc.nasa.gov/project/ACEPOL/10.5067/SUBORBITAL/ACEPOL2017/DATA001>

The DOI alone is most appropriate in the long term, since the URL may change.

This should resolve most of the reviewer's problems accessing data. We should also note that AERONET and CARB are externally collected and archived data that were not a part of the ACEPOL field campaign. ACEPOL flights targeted AERONET and CARB ground sites so that

data can be compared to those observations, but the structure of the archive is outside of our control. That said, data are relatively accessible given site name locations described in Table 4.

Comments:

1. Calibrations: The calibrations effect, before and after the calibration of the observational data, is not clear. The details of flights are outlined in Table 4. Please provide results (in figures, etc) comparing raw data with the calibrated data.

The calibration techniques vary considerably amongst the airborne instruments, are quite involved, and are not necessarily unique to the ACEPOL field campaign. For that reason, we cite the relevant literature for each instrument in the appropriate descriptive sections (3.1 and 3.2). Intercomparison of instrument observations referenced in Table 2 targets 1a-1c are the subject of ongoing research. When available, appropriate literature have been cited (e.g. Smit et al, 2019).

2. What are the variables observed during the 9 flights? What are the time resolution of data of each observed variable?

This is described in Table 1, and sections 3.1 and 3.2.

3. Test of data accessibility from Table 3:

ASDC: <https://eosweb.larc.nasa.gov/10.5067/SUBORBITAL/ACEPOL2017/DATA001>
[screen capture page not found]

(see above comments)

AirMSPI
https://eosweb.larc.nasa.gov/project/airmspi/airmspi_table/10.5067/AIRCRAFT/AIRMSPI/ACEPOL/RADIANCE/ELLIPSOID_V006

[screen capture page not found]

(see above comments)

https://eosweb.larc.nasa.gov/project/airmspi/airmspi_table/10.5067/AIRCRAFT/AIRMSPI/ACEPOL/RADIANCE/TERRAIN_V006

[screen capture page not found]

(see above comments)

GroundMSPI :
https://eosweb.larc.nasa.gov/project/airmspi/airmspi_table/10.5067/GROUND/GROUNDMSPI/ACEPOL/RADIANCE_v009

[screen capture page not found]

(see above comments)

AERONET <https://aeronet.gsfc.nasa.gov/>

[screen capture for AERONET website]

Q: Where to find data relevant to the calibration of the 9 ER-2 flights described in Table 2?

Relevant AERONET sites (observed for targets 2a and 2b) are described with their time in Table 4. Data are accessed on the site using that information. i.e. click the map, select the site, select date and time, etc.

CARB <https://www.arb.ca.gov/adam/index.html>

[screen capture for CARB website]

Q: Where to get data relevant to 9 ER-2 flights in this work from this page?

This is similar to AERONET: using the information in Table 4, one must search the CARB database

4. Test of data accessibility from Abstract and reference ACEPOL Science Team, 2017:
doi:10.5067/SUBORBITAL/ACEPOL2017/DATA001

Test results: I was not able to find data from input above line to google.

For DOI's it is best to use doi.org

But I was managed to find data from following link:

https://asdc.larc.nasa.gov/project/ACEPOL/ACEPOL_AircraftRemoteSensing_CPL_Data_1

[screen capture of ASDC website]

After trying to Get Dataset, with OPENDATA selected in Additional Options, following page popped up:

[screen capture of flight display and ordering system]

Even in here, it is still unclear where and how to view the flight data?

This is a data ordering system, which gives the user the means to sort available data in time and space. You should have the option to download the data directly from that page, or order multiple granules of data. The (?) icon at the top right has more information on how this system works.

The Aerosol Characterization from Polarimeter and Lidar (ACEPOL) airborne field campaign

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Abstract.

In the fall of 2017, an airborne field campaign was conducted from the NASA Armstrong Flight Research Center in Palmdale, California to advance the remote sensing of aerosols and clouds with Multi-angle Polarimeters (MAP) and Lidars. The Aerosol Characterization from Polarimeter and Lidar (ACEPOL) campaign was jointly sponsored by NASA and the Netherlands Institute for Space Research (SRON). Six instruments were deployed on the ER-2 high altitude aircraft. Four were MAPs: the Airborne Hyper Angular Rainbow Polarimeter (AirHARP), the Airborne Multiangle SpectroPolarimetric Imager (AirMSPI), the Airborne Spectrometer for Planetary EXploration (SPEX Airborne) and the Research Scanning Polarimeter (RSP). The remainder were Lidars, including the Cloud Physics Lidar (CPL) and the High Spectral Resolution Lidar 2 ([HSRL-2](#)). The southern California base of ACEPOL enabled observation of a wide variety of scene types, including urban, desert, forest, coastal ocean and agricultural areas, with clear, cloudy, polluted and pristine atmospheric conditions. Flights were performed

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in coordination with satellite overpasses and ground based observations, including the Groundbased Multiangle SpectroPolarimetric Imager (GroundMSPi), sun photometers, and a surface reflectance spectrometer.

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ACEPOL is a resource for remote sensing communities as they prepare for the next generation of spaceborne MAP and lidar missions. Data are appropriate for algorithm development and testing, instrument intercomparison, and investigations of active and passive instrument data fusion. They are freely available to the public, at 10.5067/SUBORBITAL/ACEPOL2017/DATA001 (ACEPOL Science Team, 2017). This paper describes ACEPOL for

45 potential data users, and also provides an outline of requirements for future field missions with similar objectives.

1 Introduction

Aerosols, clouds, and their interactions are the largest source of uncertainty in estimates of the radiative forcing of the Earth. Reducing this uncertainty requires global observations to act as constraints for studies of the role of aerosols and clouds in a changing climate (Boucher et al., 2013). While existing passive orbital sensors show observational skill, they are limited in

50 their consistency and under-determined for retrieval of the relevant geophysical parameters (Mishchenko et al., 2004). In other words, the remote sensing retrieval solutions are often non-unique, and require the use of constraints in the form of, for example, aerosol models, which may or may not represent geophysical reality. For this reason, the 2007 Decadal Survey of

the National Research Council recommended to the National Aeronautics and Space Administration (NASA) the creation of the Aerosol-Cloud-Ecosystems (ACE) Mission, with the stated goal to reduce climate forcing uncertainty of aerosol-cloud

55 interactions, and to better understand ocean ecosystem carbon dioxide uptake (NRC, 2007). This recommendation led to the ACE pre-formulation mission study (da Silva, et al, 2019). This study (2008-2018) was devoted to technological and scientific developments to address aerosol-cloud climate forcing uncertainty along with improved observations of ocean color to better

60 characterize ocean biology. Designs for an ocean color instrument were enhancements of previous ocean color satellite instruments, such as the Sea-viewing Wide Field-of-view Sensor (SeaWiFS, McClain et al, 2004). These prototypes were, in part, developed and tested by deploying airborne instruments on high altitude aircraft. Thus, airborne field campaigns were a

ACEPOL was one of several field campaigns supported by ACE, with the specific objective of testing lidar and Multi-angle Polarimeter (MAP) instruments in a variety of conditions. Such instruments reduce aerosol and cloud climate forcing

65 uncertainties by accurately determining aerosol and cloud optical and microphysical properties and vertical distribution. They are, however, diverse in their measurement characteristics, retrieval approaches, and capability (Weitkamp, 2006, Kokhanovsky et al., 2015, Dubovik et al., 2019). Six of these instruments were installed on the ER-2 aircraft, which, because of its capability for high altitude, long range flights, provides an ideal platform for exploring measurement concepts of relevance to ACE. Two were Lidars: the Cloud Physics Lidar (CPL) and the High Spectral Resolution Lidar 2 (HSRL-2),

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while the remaining four instruments were MAPs: the Airborne Hyper Angular Rainbow Polarimeter (AirHARP), the Airborne Multiangle SpectroPolarimetric Imager (AirMSPI), the Airborne Spectrometer for Planetary EXploration (SPEX Airborne) and the Research Scanning Polarimeter (RSP). See [Table 1](#) for a summary of the characteristics of these instruments, and Section 3 for more detail.

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In addition to supporting ACE, an ACEPOL objective was to provide a calibration reference for the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument on the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) mission (Winker et al., 2009). This was performed with coordinated flights along the satellite ground track at the time of overpass. A coordinated underflight of the Cloud-Aerosol Transport System (CATS) orbital lidar (McGill et al., 2015) were also conducted. The third sponsor of the ACEPOL field campaign was the Netherlands Institute for Space Research (SRON), partly funded through the NWO/NSO project ACEPOL (ALW-GO/16-09), to further advance aerosol measurement capabilities from space and the technological development of the SPEX Airborne instrument in particular.

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ACEPOL consisted of nine flights from the Armstrong Flight Research Center (AFRC) in Palmdale, California in October and November of 2017. AFRC is the home base of the ER-2 aircraft and has excellent supporting facilities. Furthermore, it is within range of a variety of types of scenes, from oceans off the California coast, urban areas in Los Angeles, intensive agriculture in the California central valley, forests in the Sierra Nevada mountains and the high desert in California, Nevada and Arizona. Aerosol and clouds within these regions are similarly varied. An additional benefit is the accessibility of many ground validation sites, in particular the aerosol observations of the Aerosol Robotic Network (AERONET, Holben et al., 1998), and desert salt pans such as Rosamond Dry Lake for which comprehensive surface reflectance characterization allows vicarious calibration of airborne sensors. Figure 1 is a pilot's photograph from the cockpit of the ER-2, which illustrates the unique, high altitude vantage point of the aircraft. [Deployment of an instrument on this aircraft is a close analog for the space environment and observation conditions](#). Figure 2 and Figure 3 show the ER-2 on the ground with a portion of the ACEPOL team, and the ACEPOL emblem, respectively. The latter indicates the position of the remote sensing instruments onboard the aircraft, with two on the fuselage, and two in each wing pod.

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Consistent with NASA's policy on data collection and availability, ACEPOL data are publicly available (see Section 3.4). The purpose of this article is to document the conditions under which these data were collected to aid their use by the scientific community, and to describe initial efforts by the ACEPOL team to analyze and compare results. As such, Section 2 describes the ACEPOL measurement objectives, while Section 3 covers instrument specifics. Section 4 chronicles the field deployment, and identifies successful observations of targets described in Section 2. Section 5 discusses the value of ACEPOL for various current and planned missions, while Section 6 concludes.

100

2 Objectives

110 The overall objectives of the ACEPOL field campaign, as is described below, were to test new observations systems, develop
new algorithms, and validate orbital observations. For that reason, a wide range of observation conditions were desired. This
differs from field campaigns investigating specific processes for the purpose of broader scientific understanding. The goals of
this campaign instead focused on improvement of measurement techniques, instrument calibration, and algorithm
development. All flights started and ended in Southern California, enabling flights over urban, rural, mountainous, desert,
115 coastal and deep ocean regions in a variety of atmospheric conditions. To better organize flight planning, the ACEPOL
measurement objectives were condensed into a list of prioritized targets, as described in Table 2 and below.

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120 Target types fell into four broad categories: calibration, geolocation, validation, and targets of opportunity. Calibration targets
(1a, 1b, and 1c) were meant to provide spatially uniform observations with which radiometric and polarimetric measurements
between multi-angle polarimeters can be compared. A similar intercomparison was performed during the Polarimeter
Definition Experiment (PODEX) between the RSP and AirMSPI instruments (Knobelspiesse et al., 2019). Intercomparison
can now be performed with those instruments plus AirHARP and SPEX Airborne. Such intercomparisons can confirm
measurement uncertainty estimates and identify calibration problems. Different scene types are useful for intercomparison:
125 cloud free ocean observations (1a) provide low reflectance, potentially highly polarized measurements, while land scenes can
have high reflectance but moderate to low polarization. Cloud scenes provide high reflectance and low polarization.
Intercomparison requires accurate geolocation, so minimizing scene heterogeneity and atmospheric variation is important.
Furthermore, scenes with distinct features, such as coastlines, were targeted to provide a geolocation reference (1d). Validation
targets are used to test the geophysical products retrieved by the airborne sensors against similar observations on the ground
(2a, 2b), by other field campaigns (2c), and by satellites (3a, 3b). Targets of opportunity are intended for algorithm development
130 and represent infrequently observed or difficult scenes. Finally, it should be noted that the target number designation roughly
indicates priority. Low numbered targets are of highest priority and are generally organized such that targets supporting
validation or calibration of radiometric quantities have greatest precedence, followed by validation of geophysical products
derived from such observations, and then special cases and difficult scenes (targets of opportunity).

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135 Most of the highest priority targets were observed successfully during ACEPOL, although conditions precluded observation
of uniform marine stratocumulus cloud decks (target 1c), and most cases of high aerosol loads. The latter was highly unusual
for this part of the world, as California's San Joaquin Valley and the Los Angeles metropolitan area are known for typically
high aerosol loads. The solution was to overfly controlled forest fire burns farther afield in Arizona. Attempted coordination
with the Coupled Air Sea Processes and EM Ducting Research (CASPER) East (Wang et al, 2018) field campaign was
140 unfortunately not possible because of scheduling difficulty and weather. Serendipitously, one flight overlapped with a flight
by the Alpha Jet Atmospheric Experiment (AJAX), which carried a payload of atmospheric gas sensors. High aerosol loads

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over the ocean (4a) were not observed, but low aerosol load overflights of an AERONET site (2b) on a platform off Long Beach, CA have become the basis for several analysis papers (e.g. Fu et al, 2019, Gao et al, 2020). Another important accomplishment was the successful overflight of Rosamond Dry Lake from multiple headings while a ground based team characterized the spectral reflectance of the lakebed. This was used to vicariously adjust the AirMSPI calibration, and serves as a reference for other measurements as well.

Furthermore, the value of ACEPOL observations exceeds these initial objectives. For example, polarimetric observations of land surfaces may be useful for assessment of Bidirectional Reflectance Distribution Function (BRDF) and Bidirectional Polarization Distribution Function (BPDF) models even by other instruments, and observations over the ocean can be used to help develop ocean remote sensing algorithms (see Section 5.4 for more details on the latter).

2.1 The Aerosol Cloud Ecosystems (ACE) mission study

ACE preformulation study activities included defining mission requirements, advancing algorithms and instrument technical readiness by convening science workshops, developing mission design white papers, and supporting new or augmenting otherwise planned field campaigns (see <https://acemission.gsfc.nasa.gov>). Technological development and scientific utilization of three classes of instruments were supported by the ACE study. These instruments included: cloud and precipitation Radars, atmospheric profiling aerosol and cloud lidars, and MAPs. Lidars and MAPs are the most relevant for aerosol remote sensing and were deployed in early 2013 for PODEX (Diner et al., 2013, Alexandrov et al., 2015, Van Harten et al., 2018, Knobelspiesse et al., 2019) and in ACEPOL during the Fall of 2017. In some ways, PODEX can be considered a precursor to ACEPOL. Both used the high-altitude ER-2 aircraft based at AFRC, flew in a variety of conditions, and deployed AirMSPI, CPL and RSP (among other instruments). PODEX also deployed the Passive Aerosol and Cloud Suite (PACS), an earlier version of AirHARP. ACEPOL offers a larger collection of more mature instruments, notably the SPEX Airborne and AirHARP polarimeters and the HSRL-2 lidar. ACEPOL offers an opportunity to also intercompare single instrument and synergistic algorithms involving lidars and MAPs.

2.2 Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) mission validation

Airborne measurements of particulate backscatter and extinction have been important for assessing CALIOP 532 nm (Powell et al., 2009; Rogers et al., 2011) and 1064 nm (Vaughan et al., 2010; 2019) level 1 attenuated backscatter profiles, level 2 aerosol optical depth (AOD) retrievals (Rogers et al., 2014), aerosol classification methodology (Burton et al., 2013), cirrus cloud properties (Yorks et al., 2011), and combined active (CALIOP) passive (Moderate Resolution Imaging Spectroradiometer, MODIS) retrievals of aerosol extinction profiles (Burton et al, 2010). Using airborne measurements to evaluate CALIOP aerosol backscatter measurements avoids uncertainties caused by systematic errors, spatial inhomogeneities, and distortions associated with using ground based lidar measurements for such validation (Gimmedstad et al., 2017).

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190 Consequently, ACEPOL also collected measurements under the CALIOP on flights conducted on October 26th, November 7th
and 9th, and under the CATS sensor on the 19th of October.

2.3 Netherlands Institute for Space Research (SRON) studies

The ACEPOL campaign served several SRON objectives related to the improvement of MAP instrument performance and
aerosol retrievals and investigation of algorithm development for aerosol retrievals using both polarimeter and lidar
195 measurements. Specifically, the SPEX Airborne instrument deployed during ACEPOL is a prototype of the SPEXone
instrument that is contributed to the upcoming NASA PACE mission, due to be launched in late 2022. Validation of the SPEX
airborne level-1 data products (radiance and Degree of Linear Polarization, DoLP) during ACEPOL serve to identify possible
improvements to be implemented in the SPEXone instrument ~~this is to be contributed to NASA's Plankton-Aerosol-Cloud-~~
~~ocean Ecosystem (PACE, Werdell et al., 2019) mission. The PACE spacecraft will fly three instruments in low earth orbit.~~
200 ~~The primary instrument is a UV-NIR imaging spectrometer with additional SWIR bands, while two MAPs will be contributed:~~
~~SPEXone, and HARP-2 (see section 3.1.1 for a description of the airborne prototype of that instrument). Additionally,~~
~~ACEPOL provides a test data set for level-2 algorithm development for SPEXone on PACE. The SRON participation in~~
~~ACEPOL was funded by the Netherlands Organization for Scientific Research (NWO) and the Netherlands Space Office~~
~~(NSO).~~

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SRON, and partly from the Netherlands Space Office (NSO). ↕

205 3 Observations

3.1 Polarimeters

3.1.1 The Airborne Hyper Angular Rainbow Polarimeter (AirHARP)

AirHARP is a wide field-of-view imaging polarimeter designed for characterization of cloud and aerosol optical properties.
AirHARP is an amplitude-splitting polarimeter: light entering the front lens is decomposed into three orthogonal linear
210 polarization states (0, 45, and 90°) by a modified three-way Phillips prism. Each polarization state is imaged by a unique
detector array, so the first three parameters of the Stokes vector (I, Q, and U) are retrieved at pixel by combining co-located
information from all three detectors. Stripe filters on the detectors define 120 distinct along track viewing angles across the
four HARP wavelengths (spectral widths): 440 (14), 550 (12), 670 (18), and 870 (38) nm, across a total swath of $\pm 57^\circ$ ($\pm 47^\circ$)
215 along-track (cross-track). 60 of these angles are at 670nm, specifically designed for studying the structure of the polarized
cloudbow. The high angular resolution (roughly 2°) enables AirHARP to measure the cloudbow structure at all individual
pixels. The remaining three wavelengths have 20 angles each for characterization of aerosols. Figure 4a shows an illustration
of the sampling scheme applied by the HARP polarimeters, where each along track viewing angle of the instrument produces
a full pushbroom image. The figure also shows an example of data collected during the ACEPOL campaign, its second

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225 deployment. The instrument's maiden field campaign was the Lake Michigan Ozone Study (LMOS) in 2017 (McBride et al.,
2020). For ACEPOL, AirHARP collected data over defined targets, as the processing speed of the onboard data acquisition
system precluded continuous data collection.

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230 AirHARP is an aircraft demonstration for the HARP CubeSat instrument, a standalone satellite that was successfully launched
on 19 February 2020 from the International Space Station (ISS) conducting Earth observations for a year-long mission. A third
member of the HARP family is the HARP2 sensor, which will provide global coverage in two days, as part of the NASA
PACE mission due to launch no earlier than 2022 (Werdell et al., 2019).

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235 AirHARP Level 0 ACEPOL data are corrected, reconstructed, geolocated, and calibrated in the Hyper-Angular Image
Processing Pipeline (HIPP) Level-1B algorithm. These data products are gridded to a horizontal resolution of 2000 pixels per
latitude degree and packaged into HDF5 files for distribution in ACEPOL data archive. A Level 2 aerosol retrieval algorithm
has been implemented using the Generalized Retrieval for Aerosol and Surface Properties (GRASP) scheme (Dubovik et al.
2011, Puthukkudy et. al 2020). Figure 4 (d) shows the AOD map retrieved using AirHARP measurements and GRASP
inversion algorithm for a smoke scene in Figure 4 (c). The magnitude and spatial variability of retrieved AirHARP AOD are
240 in good agreement with collocated lidar (i.e., HSRL-2) observations (Puthukkudy et. al 2020) and are also consistent with the
AOD retrieved from AirSPEX and RSP instruments (Fu et al., 2020). Cloud droplet size distribution retrievals are implemented
using a traditional parametric fit to Mie scattering curves for liquid water droplets (McBride et al. 2020). Retrievals of ice
cloud characteristics, aerosols above clouds, ocean and surface reflectance properties, and atmospheric correction are also
important potential uses of HARP data.

245 3.1.2 The Airborne Multiangle SpectroPolarimetric Imager (AirMSPI)

The Airborne Multiangle SpectroPolarimetric Imager (AirMSPI, Diner et al., 2013b) is pushbroom imaging camera used for
the characterization of atmospheric aerosols and clouds. In addition to radiometric channels, AirMSPI employs photoelastic
modulators (PEMs) to enable accurate measurements of the degree and angle of linear polarization (Diner et al., 2010; van
Harten et al. 2018). These polarimetric data help discriminate between different aerosol particle types, which is crucial to
250 improving our understanding on climate and air quality. The instrument flies aboard NASA's high-altitude ER-2 aircraft, and
acquires Earth imagery with ~10 m spatial resolution across a 9km wide swath. Radiance data are obtained at 355, 380, 445,
470, 555, 660, 865, 935 nm. The polarimetric channels at 470, 660, and 865 nm report both radiances and the linear polarization
Stokes components Q and U. AirMSPI is a precursor to the future Multi-Angle Imager for Aerosols (MAIA) satellite
instrument (see Section 5.3), which will be used to improve our understanding of the health risks associated with airborne
255 particulate matter.

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290 The AirMSPI camera is mounted on a motorized single-axis gimbal to enable multiple views of a science target from different along-track view angles. The number of views and specific set of angles for each observing sequence is programmable prior to flight. While approaching the target in a straight and level flight line, the pilot presses one of three buttons to start the corresponding multi-angle acquisition sequence. Figure 5 shows example imagery of the sequences used during the ACEPOL campaign. All 3 modes begin and end with views of the onboard dark target and polarization validator light source.

295 AirMSPI observed a total of 24 targets in the 9-angle step-and-pseudostare mode, 32 targets in the 15-angle mode, and 209 continuous sweep images. AirMSPI LIB2 geolocated radiometric and polarimetric data and quicklooks are available as noted in Section 3.4. For a further analysis, and comparison with other MAPs and Lidars during ACEPOL, see Fu et al. 2020.

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3.1.3 The Research Scanning Polarimeter (RSP)

300 A pair of RSP instruments (denoted RSP1 and RSP2; the latter was used in ACEPOL) have been deployed on more than 25 field missions in the last 20 years. The RSP is an airborne multi-angle and multi-spectral polarimeter that continuously scans in the aircraft along-track direction. During a complete scanner rotation, a total of 205 samples, each with a 0.8° (14 mrad) field of view, are collected. The 205 samples include: 152 views between 60° forward and aft of the normal to its baseplate; 10 samples viewing an internal dark reference and 43 samples through an earth viewing polarization scrambler. Samples are obtained by a rotating polarization compensated mirror assembly with six bore-sighted telescopes, to simultaneously obtain Stokes parameters 9 spectral bands. Each telescope uses a Wollaston prism to split the incoming intensity into two spatially separated orthogonally polarized components, which are then further split and passed through dichroic filters, defined by the spectral bandpass: (full width half maximum bandwidths in parentheses) 410.3 (30), 469.1 (20), 555.0 (20), 670.0 (20), 863.5 (20), 960.0 (20), 1593.5 (60), 1880.0 (90) and 2263.5 (120)nm. On the ER-2, the un-vignetted viewing angle range is from 65° aft to 45° forward, for a total of 120 samples. The single nadir ground pixel size from an altitude of 20 km is 280 m, and successive pixels partially overlap.

310 RSP2 was calibrated in the Airborne Sensor Facility at NASA Ames Research Center before and after ACEPOL. Radiometric calibration was stable to within roughly 1% for all bands, except for 410.3 nm, where a 4% decrease in radiometric throughput was observed (polarimetric calibration was stable to within $\sim 0.1\%$). Data processing to level 1b (calibrated and geolocated at-sensor measurements) consists of dark subtraction for each scan and application of calibration coefficients to generate Stokes parameters, together with the geolocation of each viewing angle sample. Processing from level 1b to level 1c consists of collocating the different viewing angles about a defined altitude, either at the ground, or at cloud top if a cloud is present. The latter requires cloud identification and a cloud top height estimate (Sinclair et al. 2017). Level 2 processing of cloudy scenes is split between water and ice clouds. Water cloud retrievals include cloud optical depth and standard bi-spectral droplet size estimates (Platnick et al. 2017), as well as both parametric (Alexandrov et al. 2012a) and non-parametric (Alexandrov et al. 2012b) droplet size distribution estimates that use polarization (Alexandrov et al. 2018). Most clouds observed during

ACEPOL were low level water clouds, but when ice clouds were detected, cloud optical depth, particle size and particle shape/roughness retrievals (Van Diedenhoven et al. 2012, 2013; Van Diedenhoven 2018) were retrieved. Level 2 processing for aerosol retrievals uses the Microphysical Aerosol Properties from Polarimetry (MAPP) algorithm (Stamnes et al. 2018). The MAPP land surface model consists of a Fresnel reflectance with shadowing for the polarized reflectance (Waquet et al. 2009) together with a RossThick (Ross, 1981, Roujean et al. 1992) LiSparse (Li and Strahler, 1992) kernel model (Wanner et al. 1995), similar to that used for operational processing of MODIS land surface products (Schaaf et al., 2002). RSP was operational for all ACEPOL flights and data are available at the ACEPOL data archive ([Section 3.4](#)). Example RSP observations of a liquid phase cloud are shown in Figure 6.

3.1.4 The Airborne Spectrometer for Planetary EXploration (SPEX Airborne)

The SPEX airborne instrument (Smit et al., 2019) employs the spectral modulation technique (Snik et al, 2009), in which the degree and angle of linear polarization are encoded in a modulation of the radiance spectrum as a function of wavelength. This modulation is achieved by placing a set of dedicated optical components (quarter wave retarder, multiple order retarder) in front of the telescope. The resulting two light beams that contain a modulation pattern as a function of wavelength (out of phase with each other) that enter a spectrometer and are focussed on a detector. Radiance measurements are obtained between 400-800 nm at the spectral resolution of the spectrometer (~2 nm), while for DoLP the spectral resolution is determined by the modulation period, which is conservatively estimated at 10 nm at 400 nm and 40 nm at 800 nm.

An example of a SPEX airborne radiance and DoLP measurement obtained during ACEPOL is shown in Figure 7.

SPEX airborne has nine viewports that are projected on one detector, at angles (+/-57°, +/-42°, +/-28°, +/-14° and 0°). The SPEX airborne cross-track swath is 6°. The data processing from level-0 (detector counts) to level-1b (calibrated and geolocated radiance and DoLP values) consists of the following steps: Dark image subtraction, spectral extraction and line-of-sight annotation, wavelength annotation, spectral alignment of the 2 modulated spectra, radiometric correction, demodulation, and geolocation. Next, data of the different viewports are all aggregated on the same spatial grid, yielding the level 1C data product, currently computed at 1x1 km² spatial resolution.

For level-2 processing (Fu et al., 2020), the SPEX airborne team has focused on aerosol retrievals, building further on the SRON aerosol retrieval algorithm previously used for POLDER-3 processing (Hasekamp et al., 2011, Lacagnina et al., 2016;2017) and groundSPEX (van Harten et al, 2014; di Noia et al, 2014). The algorithm has been extended from a bi-modal retrieval scheme to a multi-mode retrieval scheme for an arbitrary number of modes (Fu and Hasekamp, 2018). For processing ACEPOL data, a setup with 5 modes has been used, where for each mode the aerosol column number is retrieved corresponding to a set of fine- and coarse mode spectrally varying refractive indices, the fraction of spherical particles (Dubovik et al, 2006), and the aerosol layer height. SPEX airborne data have been processed using 16 discrete wavelengths between 450 and 750

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355 nm. Wavelengths less than 450 nm and greater than 750 nm are excluded because of lower data quality. SPEX airborne was operational for all ACEPOL flights, and data are available at the ACEPOL data archive.

3.2 Lidars

3.2.1 The Cloud Physics Lidar (CPL)

360 The Cloud Physics Lidar (CPL) is a nadir-pointing, multi-wavelength (355, 532, 1064 nm) elastic backscatter lidar that measures vertical profiles of cloud and aerosol properties (McGill et al. 2002). CPL has participated in numerous field campaigns since its first deployment in 2000 on the ER-2, often in tandem with the other remote sensing instruments involved in ACEPOL. Raw CPL data is calibrated by normalizing the 355, 532 and 1064 nm signal to the Rayleigh (molecular) backscatter between 15 and 18 km, creating vertical profiles of the total attenuated backscatter (McGill et al., 2007). CPL data products retrieved from the calibrated backscatter include vertical profiles of depolarization ratio, particulate backscatter coefficient, and particulate extinction coefficients, as well as layer properties such as top/base altitudes, aerosol type, and optical depth (Yorks et al., 2011; Hlavka et al., 2012).

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375 CPL data products, with vertical resolution of 30 m and 1 sec frequencies (~200 m horizontal resolution), enable a wide-range of applications including the analysis of cloud properties (McGill et al., 2004; Bucholtz et al., 2010; Yorks et al., 2011; Alexandrov et al., 2015), as well as aerosol and dust properties (McGill et al., 2003; Nowotnick et al., 2011; Wu et al., 2016). CPL data from ACEPOL are fully processed and data products available at the ACEPOL data repository. However, an electronics controller failed in the CPL laser during the second flight of the campaign. The cause of this failure was not immediately apparent, and there was no time to take the instrument out of service during the ACEPOL campaign. Thus, the ACEPOL CPL data products after the first flight are non-standard, as they required more averaging, sometimes as much as 10 sec (2 km horizontal), and removal of some data at specific wavelengths due to poor quality. [Nevertheless, data are useful for validation of CALIPSO \(McGill et al. 2007, Yorks et al., 2011b, Hlavka et al., 2012\) and CATS data \(Yorks et al., 2016, Pauly et al. 2019.\)](#)

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3.2.2 The High Spectral Resolution Lidar (HSRL-2)

380 HSRL-2 is the second generation airborne High Spectral Resolution Lidar developed at NASA Langley Research Center. Like the first generation HSRL-1 (Hair et al., 2008), HSRL-2 independently measures aerosol backscatter and extinction (532 nm) using the HSRL technique, aerosol backscatter (1064 nm) using the standard backscatter technique (Müller et al. 2014, Sawamura et al., 2017), and aerosol depolarization at both wavelengths. HSRL-2 adds measurements of aerosol backscatter and [extinction](#) at 355 nm using the HSRL technique as well as measurements of aerosol depolarization at 355 nm. These
385 HSRL-2 measurements are used to compute AOD as well as the aerosol extinction/backscatter ratio ('lidar ratio') at 355 and

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390 532 nm. Rogers et al. (2009) evaluated the HSRL extinction coefficient profiles and found that the HSRL extinction profiles
are within the systematic errors of airborne in situ measurements at visible wavelengths. Derived products include, first,
estimates of planetary boundary layer heights which use the vertically resolved profile measurements of aerosol backscatter to
derive aerosol mixed layer heights during the daytime (Scarino et al., 2014). Second, aerosol classification, which uses an
algorithm to interpret the information about aerosol physical properties indicated by the HSRL-2 aerosol intensive parameters
to qualitatively infer aerosol type (Burton et al., 2012). HSRL-2 measurements have also been used to retrieve height-resolved
395 parameters such as aerosol effective radius and concentrations (number, surface, volume) (Müller et al. (2014), Sawamura et
al., 2017).

HSRL-2 has been deployed on various NASA aircraft for both NASA and DOE field missions (Berg et al., 2016; Sawamura
et al., 2017; Burton et al., 2018). During ACEPOL, HSRL-2 operated autonomously from the NASA ER-2 aircraft. When
400 operated from the ER-2, the nominal HSRL-2 aerosol backscatter profiles are reported at a vertical resolution of 15 m and a
horizontal/temporal resolution of 1-2 km (10 seconds). Aerosol depolarization ratios at all three wavelengths are reported at
the same resolutions. For ACEPOL, aerosol extinction, AOD, and lidar ratio from the HSRL methodology are not available in
some cases, particularly when the aerosol loading was small. In these cases, the aerosol extinction at 355 nm and 532 nm is
derived using the aerosol backscatter and an assumed lidar ratio of 40 sr and reported at the backscatter resolution. In other
405 cases where the HSRL method is available for extinction products, they are reported at 150 m vertical resolution and at
temporal resolution of 60s generally and 10s within smoke plumes. Calibrated aerosol backscatter derived using the HSRL
method is available in all cases. Problems with the ER-2 coolenol pump and a circuit breaker caused HSRL-2 data gaps on the
October 27 flight and loss of HSRL-2 data on the November 1 flight.

3.3 Ground observations

410 Ground based observations are valuable in that they can be used to validate or calibrate aircraft instrument measurements, or
provide context for those observations. While not part of the ACEPOL field campaign, ground sites of two instrument networks
served as targets for overflights. These networks (the Aerosol Robotic Network, or AERONET, and air quality monitors of the
California Air Resources Board, or CARB) host their data in separate archives that are not under direct control of ACEPOL
participants. A third effort, also ground based, involved deployment of radiometric and atmospheric measurement at Rosamond
415 Dry Lake. The collection of these data were funded by ACEPOL and are archived at the locations in Table 3.

3.3.1 Aerosol Robotic Network (AERONET) sites

The Aerosol Robotic Network (AERONET, Holben et al, 1998) is a system of sun photometers used to produce global
measurements of AOD, intensive properties (e.g. refractive index, size distribution), and precipitable water. This NASA
product provides data recorded every 15 minutes utilizing many spectral bands, and are available at the AERONET archive
420 (aeronet.gsfc.nasa.gov). During ACEPOL, the Modesto, Fresno-2, CalTech, and Bakersfield sites in California were

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operational, and were routinely targeted. Additional AERONET sites that were targeted during the campaign are the USGS
425 Flagstaff site in Arizona and the USC SeaPrism site. The latter is part of a sub-network designated AERONET-Ocean Color
(AERONET-OC). This network comprises enhanced instruments that have the ability to determine water-leaving radiance in
addition to aerosol optical properties (Zibordi et al, 2009).

3.3.2 California Air Resources Board (CARB) sites

Air particulates are measured by the California Air Resources Board (CARB) throughout the state. A majority of CARB sites
430 report PM_{2.5} (particulate matter with an an aerodynamic diameter of less than 2.5 microns) and PM₁₀ (particulate matter with a
diameter of less than 10 microns), as determined by a variety of measurements, including particle counting and mass
spectrometry. Gaseous criteria for air pollutants that are regulated in California and at the national level are also measured and
reported to ensure compliance with U.S. Environmental Protection Agency (U.S. EPA) air quality standards, and are stored at
the CARB archive (<https://www.arb.ca.gov/adam/index.html>).
435

In addition to CARB total PM monitors, several speciated EPA PM monitors are located in California's San Joaquin Valley
(SJV) including Modesto, Fresno, Visalia, and Bakersfield. The speciated PM monitors in Modesto, Fresno and Bakersfield
are collocated with AERONET instruments making these sites very useful for determining connections between near-surface
PM loading and atmospheric aerosols. Modesto, Fresno, and Bakersfield sites were regularly targeted throughout the
440 campaign.

3.3.3 Rosamond Dry Lake ground instrumentation

Vicarious calibration (VicCal) is the process of calibrating an on-orbit or aircraft sensor by observation of an Earth target
which is characterized for its optical properties. A radiative transfer program is then used to propagate the surface
measurements into a radiance incident on the flight sensor. Ground measurements made in support of ACEPOL vicarious
445 calibration were performed on October 25, 2017, at Rosamond Dry Lake (34.858704° N, 118.07638° W). This included
measurements of surface reflectance and total column optical depth at the time of overflight, roughly 18:00 UTC. Data were
processed at JPL and are hosted in the ACEPOL archive. These data were used by the AirMSPI team to derive a multiplier
needed to adjust the laboratory-derived radiometric gain coefficient. For the Rosamond VicCal, the ratio of radiances using
the laboratory calibration to the VicCal measured radiances was found to be low for the UV bands (0.85), but within 2% of
450 unity for the remaining visible bands. The discrepancy in the UV bands is under investigation, but one error candidate is the
low light level for these bands during the laboratory calibration.

The VicCal campaign at Rosamond included measurements of surface reflectance and total column optical depth at the time
of overflight, roughly 18:00 UTC. Results of these measurements are shown in Figure 8 and Figure 9. AOD was measured by
455 two Microtops and a Reagan sunphotometer. The Microtops are handheld instruments, with spectral bands at 440, 675, 870,

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938, and 1020 nm. The Reagan sunphotometer (Bruegge et al. 1992; Shaw et al. 1973), built at the University of Arizona, is an auto-tracking sunphotometer, with channels at 370, 400, 440, 520, 620, 670, 780, 870, 940, and 1030 nm. The instrument was calibrated via the Langley method by taking early morning data the day before the ER-2 overflight. A discrepancy is noted in the Microtops data, perhaps due to an error in its surface pressure. As the Reagan instrument was calibrated in-situ, its output was considered higher in accuracy, and used in the AirMSPI VicCal. Also shown in Figure 8 is the Junge model fit to the Microtops data, which assumes a linear relationship on a log-log scale of aerosol optical depth versus wavelength. Surface reflectance was measured by the Analytical Spectral Devices (ASD) FieldSpec 4 instrument. This measures from 350 to 2500 nm with 1 nm samples with resolution at 3 nm (VIS, NIR) and 10 nm (SWIR). Data were taken over a 500x500 m area, along with spectra of a Spectralon 100% diffuse reflectance standard. To report radiances, the Spectralon data are interpolated at the target sample times, and corrected for Spectralon bi-directional reflectance. The ratio of the target to interpolated Spectralon data provides a per-sample reflectance, which are then averaged to provide a site average.

Operating alongside the vicarious calibration instrumentation was the Ground-based Multiangle SpectroPolarimetric Imager (GroundMSPI) instrument (see Fig. 8). The specifications of the GroundMSPI camera are similar to AirMSPI (see Section 3.1.2), including the 8 spectral bands within 355-935 nm, with 470, 660, and 865 nm being polarimetric. The camera is mounted ~1m from the ground on a motorized altazimuth tripod. GroundMSPI performed continuous elevation scans at different azimuths to image the surface as well as the clear sky. The surface observations provide a direct measurement of the polarized bidirectional reflectance distribution function (p-BRDF), including potential spectral variance, whereas the sky radiance and polarization data serve as input for aerosol retrievals, either independently or combined with the airborne sensors. On November 7, 2017, GroundMSPI performed sky scans at the Fresno AERONET station during ER2 and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) overpasses. GroundMSPI L1B2 rectified and co-registered radiometric and polarimetric data and quicklooks are available as noted in Section 3.4.

3.4 Data availability

The primary repository for ACEPOL data is the NASA Atmospheric Science Data Center (ASDC), at the Langley Research Center. AirMSPI and GroundMSPI data are stored separately at the ASDC, while AERONET data are located at their own archive. Air quality from California are stored at the CARB website. AJAX data are available by request to the PI, Dr. Laura Iraci at NASA ARC. The DOI for the primary database is: 10.5067/SUBORBITAL/ACEPOL2017/DATA001 (ACEPOL Science Team, 2017), while for AirMSPI it is 10.5067/AIRCRAFT/AIRMSPI/ACEPOL/RADIANCE/ELLIPSOID_V006 and 10.5067/AIRCRAFT/AIRMSPI/ACEPOL/RADIANCE/TERRAIN_V006 (ACEPOL AirMSPI Science Team, 2017). GroundMSPI data are at 10.5067/GROUND/GROUNDMSPI/ACEPOL/RADIANCE_v009 (GroundMSPI Science Team, 2017). Table 3 lists further details of these archives.

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490 4 Deployment

4.1 Flight planning

Daily flight planning was informed by weather and aerosol forecasts from NASA’s Global Modeling and Assimilation Office (GMAO, <https://gmao.gsfc.nasa.gov>) and the European Center for Mid-Range Weather Forecast (ECMWF, <http://ecmwf.int>), satellite imagery from several geostationary and polar orbiting satellites (e.g., GOES-16, MODIS, VIIRS), and fire weather outlooks from NOAA’s Storm Prediction Center (https://www.spc.noaa.gov/products/fire_wx). Flight plans were drafted based on forecast information and adjusted in real-time to account for the rapid changes in fire and weather conditions. See Table 4 for detailed information about each flight. This table lists relevant information about each flight, including observed targets, instrument status, and coordinated observations with satellite, ground or other aircraft observations. Local time at AFRC is UTC-08:00. Scenes of particular interest are highlighted in bold. The “Moving Lines” flight planning tool (LeBlanc, 2018) was used to prepare for all flights, along with weather forecasting support of the NASA Global Modeling and Assimilation Office (GMAO).

4.2 Aircraft operations

All airborne sensors were deployed together on the NASA Lockheed Earth Resources (ER-2) aircraft, based at the NASA AFRC in Palmdale, California. The ER-2 is a high-altitude aircraft, capable of flying up to roughly 21km (68,000 feet), above most of the Earth’s atmosphere. Flights were contained within the continental United States and offshore, primarily in California, Nevada and Arizona. The aircraft altitude, range, and the variety of conditions within that range made the ER-2 deployment from AFRC an excellent orbital analogue platform.

[Figure 10 Flight tracks for the ACEPOL field campaign](#) is a graphical illustration of ACEPOL flight tracks with more information in Table 4. Generally, atmospheric conditions during ACEPOL were clear, with very low aerosol loads, and few clouds. The range of the ER-2 helped compensate for these somewhat unusual low aerosol conditions, providing for cloud observations in northern California or offshore, and deployments east over Arizona to overfly prescribed forest fire burns near the Grand Canyon in Arizona.

One of the priorities of ACEPOL was coordinated overflights of ground sites to validate retrievals by the remote sensing instruments. AERONET sun photometers were overflown on all days except the test flights on October 19th and November 3rd. Often, these overflights were planned so that the aircraft heading was close to the Solar Principal Plane (SPP), which maximizes the scattering angle range of MAP observations in order to increase the measured information. The AERONET-OC site “USC_SEAPRISM”, located on an oil platform off Newport Beach, California, was of particular interest because of the capability for concurrent ocean and atmosphere measurements. This site was targeted on multiple days. Since CARB

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Deleted: Figure 10 Flight tracks for the ACEPOL field campaign.

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particulate matter monitoring sites are often co-located with AERONET sites (especially in the California Central Valley), these were frequently monitored as well.

530 On the last ACEPOL flight (November 9th), there was a serendipitous overflight of a (lower altitude) flight by an Alpha Jet stationed at the NASA Ames Research Center (ARC) as part of the Alpha Jet Atmospheric Experiment (AJAX) flight series (Hamill et al, 2016). The Alpha Jet was instrumented with a wing pod sampling gas concentrations of CO₂, CH₄, H₂O, O₃ and HCHO, plus 3D wind speeds, temperature and pressure, and proceeded the ER-2 by about one hour in an area of the eastern Sierra Nevada Mountains.

4.3 Example scene

535 ACEPOL brings together four multi-angle polarimeters and two lidars which have disparate observation characteristics. An example of this is shown in Figure 11. This scene, an overflight of prescribed burns near the Grand Canyon on October 27, 2017, was observed by all instruments, although CPL and RSP data are omitted from this figure for clarity. Aerosol Backscatter in the lidar data (HSRL shown, CPL omitted) show smoke in the process of either being lofted by surface topography or trapped by that topography. Large scale AirHARP data indicate the horizontal extent of the smoke plume, while high spatial resolution AirMSPI data demonstrate fine scale spatial variability. Continuous sampling polarimeters (SPEX Airborne, shown, RSP, omitted) capture the atmospheric state for the entire flight. All instruments can be used to further derive the aerosol optical properties to varying degrees of success, depending on observation information content and retrieval algorithm design. Because of the overlapping nature of such observations, these scenes provide a test of retrieval capability ([e.g. Fu et al., 2020](#), [Gao et al., 2020](#), [McBride et al., 2020](#), [Puthukkudy et al., 2020](#)). They can also be used to investigate algorithms that incorporate data from multiple instruments.

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5 Value for future missions

5.1 Aerosol, Cloud, Convection and Precipitation (ACCP) mission study

ACEPOL was designed to evaluate instrument designs under consideration for the ACE mission study, which had scientific goals that are still relevant today. As evidence, the 2017 Decadal Survey of the National Academies of Sciences, Engineering, and Medicine (National Academies of Sciences, Engineering, and Medicine, 2018) identified targeted observables (“Aerosols” and “Clouds, Convection & Precipitation”). In response, NASA is now conducting the Aerosol, Cloud, Convection and Precipitation (ACCP) pre-formulation study (<https://science.nasa.gov/earth-science/decadal-accp>). Spaceborne versions of the airborne lidar and polarimeters that participated in ACEPOL are under consideration for ACCP. Hence, ACEPOL data play an important role in ACCP activities.

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555 **5.2 Hyper Angular Rainbow Polarimeter (HARP) CubeSat**

AirHARP provides an excellent proxy dataset for the development of HARP CubeSat algorithms. The two instruments are nearly identical, although AirHARP experienced temperature, vibrational, and humidified conditions on aircraft that are not present in space. Like AirHARP, the HARP CubeSat does not have an on-board calibrator, so many of the correction techniques used on the AirHARP data will carry over to the CubeSat data. However, by pointing the spacecraft, the HARP
560 CubeSat sensor is capable of lunar, limb, and deep space views, as well as coverage over a larger variety of surfaces, which may improve post-processing and vicarious data calibrations.

The synergy between AirHARP and other ACEPOL instruments provides excellent opportunities to study design and sampling, with relevance to HARP Cubesat. Because of altitude and bandwidth limitations, the instruments have different spatial resolutions. For AirHARP, ground pixel is much smaller (55m) than it will be from HARP CubeSat (about 4km at nadir). AirHARP retrievals can be used to study small-scale variabilities in a cloud field (McBride et al. 2020) and smoke plume (Puthukkudy et. al 2020). These features will be much less resolved in HARP CubeSat data, which is better suited for intercomparisons with MODIS and other satellite instruments. As technology demonstration, the amount of data collected by HARP CubeSat is severely constrained by spacecraft storage and downlink capabilities allowing for a single scene per day. This limitation is not present in future versions of the HARP payload, such as HARP2 on PACE.
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5.3 Multi-Angle Imager for Aerosols (MAIA)

NASA selected the Multi-Angle Imager for Aerosols (MAIA) investigation (Diner et al., 2018) as part of the third Earth Venture Instrument (EVI-3) solicitation. MAIA’s primary objective is to assess the impacts of different types of airborne particulate matter (PM) on human health, where “type” refers to the proportions of aerosols having different sizes, shapes,
575 compositions and speciated particulate matter counts. The satellite instrument contains a pushbroom multispectral and polarimetric camera mounted on a two-axis gimbal. Along-track pointing (up to $\pm 60^\circ$) enables multiangle observations over a discrete set of globally distributed target areas, while cross-track pointing provides the camera with a wide cross-track field of regard ($\pm 45^\circ$), permitting frequent revisits of the designated targets. MAIA makes use of the same dual-PEM polarimetric imaging approach as AirMSPI and extends the spectral range into the shortwave infrared (SWIR). The camera includes 14
580 spectral bands in the ultraviolet (UV), visible/near-infrared (VNIR), and SWIR, of which 3 are polarimetric (442, 645, and 1040 nm). Channels near the O₂ A-band (749, 762.5 nm) are included to explore sensitivity to aerosol layer (and cloud) height. Launch into a 740-km sun-synchronous, ascending node orbit with 10:30 am equator-crossing time is planned for mid-2022 aboard the General Atomics Orbital Test Bed-2 spacecraft. MAIA measurements will be used to retrieve total AOD and column effective aerosol optical and microphysical properties at 1-km spatial resolution, using an optimal estimation algorithm (Xu et al., 2017). A geostatistical regression modeling framework will be used to transform column aerosol optical and microphysical
585 properties to speciated, near-surface PM concentrations (Kalashnikova et al, 2018). During ACEPOL, AirMSPI collected

Deleted: The synergy between AirHARP and other ACEPOL instruments provides excellent opportunities to study design and sampling, with relevance to HARP Cubesat. Because of altitude and bandwidth limitations, the instruments have different spatial resolutions. For AirHARP, it is much smaller (roughly 55m at nadir) than it will be from HARP CubeSat (about 4km at nadir). AirHARP retrievals can be used to study small-scale variabilities in a cloud field or smoke plume. These features will be much less resolved in HARP MODIS data, which is better suited for intercomparisons with MODIS and other satellite instruments. As technology demonstration, the amount of data collected by HARP CubeSat is severely constrained by spacecraft storage and downlink capabilities allowing for a single scene per day. This limitation is not present in future versions of the HARP payload, such as HARP2 on PACE. ¶

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imagery over speciated PM and AERONET sites, while [HSRL-2](#) obtained independent data regarding aerosol types and their vertical distributions, making the campaign a valuable source of information for testing and validation of MAIA algorithms.

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605 5.4 Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission

The NASA PACE mission, due to be launched in late 2022, will contain three instruments. The primary instrument is the Ocean Color Imager (OCI), a UV-VIS spectrometer designed for Ocean Color remote sensing applications. OCI also has channels in the SWIR, and will also perform retrievals of aerosol, cloud, and land surface geophysical properties. The PACE payload will also contain two, contributed, MAPs. Airborne prototypes of these instruments, with similar characteristics, were
610 flown as part of ACEPOL. AirHARP is the airborne prototype of PACE/HARP2, while SPEX Airborne is the prototype of PACE/SPEXone (Werdell et al, 2019, Hasekamp et al., 2019). For these reasons, ACEPOL data provide a valuable resource for the development of remote sensing strategies for PACE, by acting as a proxy for the MAPs on PACE. The spectrometer characteristics of SPEX Airborne can also serve as a proxy for OCI UV-VIS spectrometer, while the SWIR channels on RSP
615 ACEPOL can be used to understand the impact of PACE design decisions. Additionally, coincident observation by other instruments, namely the CPL and [HSRL-2](#) lidars, can be used to validate assessed retrievals. Studies of these observations in the context of PACE are active and underway (e.g. Smit et al., 2019, Fu et al, 2020).

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5.5 Upcoming SPEX Airborne deployments

[As part of the EU-Horizon 2020 project SCARBO \(Space Carbon Observatory\) it is planned that SPEX airborne will participate in an airborne campaign in September 2020 \(depending on the COVID-19 situation\), flying together with two instruments that measure CO₂. The goal is to use aerosol measurements from SPEX airborne to improve CO₂ retrievals from 2 instruments dedicated to CO₂ retrieval: the MAMAP \(Methane Airborne Mapper\) spectrometer \(Krings et al., 2011\) and the NanoCarb. interferometer \(Ferrec et al, 2019\) The flights will depart from Toulouse and will cover \(parts of\) France, Spain, Italy and Germany. The aircraft for the SCARBO campaign will be a Falcon that will fly between 2 and 10 km altitude. For
625 upcoming deployments, the data-processing chain \(from level 0 to level-2\) will make full use of the algorithm processor performed for ACEPOL \(Smit et al., 2019; Fu et al., 2020\).](#)

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6 Conclusions

The ACEPOL field campaign explored techniques for remote sensing of aerosol and cloud optical properties [with a variety of MAP and lidar designs. Roughly four categories of observations were targeted: those that aid in radiometric property calibration or validation, those supporting geolocation tests, those for validating the retrieval of derived geophysical parameters, and 'targets of opportunity' representing difficult or rarely observed scenes to use in algorithm development. The field campaign was largely a success: all instruments were operational with limited outages for technical or engineering](#)

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[problems, and data have been processed and archived. Conditions were sufficient to achieve most of the primary objectives, although unusually low aerosol loads compelled the research aircraft to target forest fires further afield.](#)

650 These co-located observations, gathered in a diversity of conditions, are a valuable resource for algorithm development, instrument design, and other studies, and are archived in publicly available databases. Furthermore, the coordination and teamwork demonstrated during this successful field campaign can serve as a model for future campaigns, especially those that have multiple objectives, instrument teams and funding institutions.

7 Acronyms and units

	ABI	Advanced Baseline Imager
655	ACCP	Aerosol, Cloud, Convection and Precipitation
	ACEPOL	Aerosol Characterization from Polarimeter and Lidar
	AERONET	Aerosol Robotic Network
	AERONET-OC	Aerosol Robotic Network – Ocean Color
	AFRC	NASA Armstrong Flight Research Center
660	AirHARP	Airborne Hyper Angular Rainbow Polarimeter
	AirMSPI	Airborne Multiangle SpectroPolarimetric Imager
	AJAX	Alpha Jet Atmospheric Experiment
	AOD	Aerosol Optical Depth
	ARC	NASA Ames Research Center
665	ASD-AC	Airborne Science Data for Atmospheric Composition
	ASDC	Atmospheric Science Data Center (at NASA Langley Research Center)
	BPDF	Bidirectional Polarization Distribution Function
	BRDF	Bidirectional Reflectance Distribution Function
	CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
670	CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
	CARB	California Air Resources Board
	CASPER	Coupled Air Sea Processes and EM Ducting Research
	CATS	Cloud-Aerosol Transport System
	CPL	Cloud Physics Lidar
675	DISCOVER-AQ	Deriving Information on Surface Conditions from Column and VERTically Resolved Observations Relevant to Air Quality
	DOE	Department of Energy

	DoLP	Degree of Linear Polarization (unitless)
	ECMWF	European Center for Mid-Range Weather Forecast
680	EPA	U.S. Environmental Protection Agency
	ER-2	Lockheed Earth Resources 2 (aircraft)
	EVI	Earth Venture Instrument
	GroundMSPI	Groundbased Multiangle SpectroPolarimetric Imager
	GMAO	Global Modeling and Assimilation Office
685	GOES-16	Geostationary Operational Environmental Satellite – 16
	GRASP	Generalized Retrieval for Aerosol and Surface Properties
	HARP2	Hyper Angular Rainbow Polarimeter – 2 (contribution to PACE mission)
	<u>HDRF</u>	<u>Hemispherical-Directional Reflectance Factor</u>
	HIPP	Hyper-Angular Image Processing Pipeline
690	<u>HSRL-2</u>	<u>High Spectral Resolution Lidar 2</u>
	LaRC	NASA Langley Research Center
	LMOS	Lake Michigan Ozone Study
	MAIA	Multi-angle Imager for Aerosols
	<u>MAMAP</u>	<u>Methane Airborne Mapper</u>
695	MAP	Multi-angle Polarimeter
	MAPP	Microphysical Aerosol Properties from Polarimetry (RSP algorithm)
	MISR	Multi-angle Imaging SpectroRadiometer
	MODIS	Moderate Resolution Imaging Spectroradiometer
	NASA	National Aeronautics and Space Administration
700	NIR	Near infrared
	NIST	National Institute of Standards and Technology
	NSO	Netherlands Space Office
	<u>NWO</u>	<u>Nederlandse Organisatie voor Wetenschappelijk Onderzoek (Netherlands Organization for Scientific Research)</u>
705	ORACLES	ObseRvations of Aerosols above CLouds and their intEractionS
	P-3	Lockheed P-3 Orion (aircraft)
	PACE	Plankton, Aerosol, Cloud, ocean Ecosystem
	<u>PACS</u>	<u>Passive Aerosol and Cloud Suite</u>
	PM	Particulate Matter
710	PODEX	Polarimeter Definition Experiment
	RSP	Research Scanning Polarimeter

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	SCARBO	Space Carbon Observatory
	SeaBASS	SeaWiFS Bio-optical Archive and Storage System
715	SeaWiFS	Sea-viewing Wide Field-of-view Sensor
	SJV	San Joaquin Valley
	SPEX Airborne	Airborne Spectrometer for Planetary Exploration
	SPEXone	Spectrometer for Planetary Exploration (contribution to PACE mission)
	SPP	Solar Principal Plane
720	sr	Steradian
	SRON	Netherlands Institute for Space Research
	SWIR	Shortwave Infrared
	TCAP	Two Column Aerosol Project
	ViCal	Vicarious calibration
725	VIIRS	Visible Infrared Imaging Radiometer Suite
	VIS	Visible (wavelengths)

8 [Author contribution](#)

730 [The ACEPOL field campaign is the product of a large team, many of whom are co-authors of this manuscript. KK lead the creation of the manuscript. HM, AdS and FCS conceived and supported the ACEPOL field campaign from NASA HQ. OH coordinated support of ACEPOL at NWO/NSO. RF and KK performed flight planning and coordinated the campaign in the field. AdS and KLDF provided meteorological support for field operations. KN lead ground and aircraft support at AFRC. JVM is the PI for AirHARP, DJD is the PI for AirMSPI, BC is the PI for RSP, OH is the PI for SPEX Airborne, MM is the PI for CPL, and JH is the PI for HSRL-2. CB lead the ground characterization at Rosamond Dry Lake. GC coordinates the data archive. All provided material for the manuscript and overall review.](#)

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9 [Competing interests](#)

[The authors declare that they have no conflict of interest.](#)

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745 The ACEPOL field campaign would not have been possible without the professionalism and energy of the ER-2 pilots and ground crew, and the overall support at the NASA Armstrong Flight Research Center.

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750 We thank the United States Forest Service, in particular Jason Clawson and David Hercher, for providing information about planned prescribed burns in the Kaibab National Forest.

The Principal Investigator for the USC_SEAPRISM AERONET-OC site is Curtiss O. Davis of Oregon State University. The site manager is Matthew Ragan of the University of Southern California.

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Figure 11 was visualized using Google Earth.

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Tables

Table 1 Airborne instrument characteristics as implemented on the ER-2 during ACEPOL. *AirMSPI has polarization sensitivity for 470, 660 and 865nm only, all other polarimeters have polarization sensitivity in all spectral channels.

Polarimeters	Principal Investigator	Spectral band centers	View angles	Spatial sampling	Spatial resolution
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AirHARP	J. Vanderlei Martins, UMBC	4: 440, 550, 670, 870 nm	670nm: 60 in, $\pm 57^\circ$ fore to aft of nadir, other channels: 20 in $\pm 57^\circ$ fore to aft of nadir	$\pm 47^\circ$ cross track FOV, targeted sampling mode, (~ 42.9 km at ground)	Gridded to 2000 pixels per latitude degree, native value: (~ 55 m)
AirMSPI	David J. Diner, JPL	8: 355, 380, 445, 470*, 555, 660*, 865*, 935 nm	Varies with targeting mode, 10 or 15 angle pseudo-stare or continuous sweep	$\pm 15^\circ$ cross track FOV (9km at ground), targeted sampling mode.	10m at ground for pseudo-stare, 25m for continuous sweep
RSP	Brian Cairns, NASA GISS	9: 410.3, 555, 469.1, 670, 863.5, 960, 1593.5, 1880, 2263.5 nm	120 from 45° fore to 65° aft of nadir	Single pixel (280m), continuous sample	280m, partial successive pixel overlap
SPEX Airborne	Otto Hasekamp, SRON	400-800 nm, ~ 2 nm resolution for intensity, 10-40 nm for polarization	9: $\pm 57^\circ$, $\pm 42^\circ$, $\pm 28^\circ$, $\pm 14^\circ$ and 0°	6° cross track, continuous sample	Native resolution ~ 200 m (nadir) - 1km ($\pm 57^\circ$).
Lidars		Backscatter channels	Extinction Channels	Horizontal resolution	Vertical resolution
CPL	Matthew McGill, NASA GSFC	355, 532, 1064 nm	-	~ 200 m	30m
HSRL-2	Chris Hostetler, NASA LaRC	355, 532, 1064 nm	355, 532nm	1-2km	15m

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1060 Table 2 Prioritized ACEPOL measurement targets. In this table, low aerosol loading indicates a mid-visible Aerosol Optical Depth (AOD) less than 0.1, moderate AOD between 0.1 and 0.2, and high AOD greater than 0.2.

Target	Description	Achieved?	Dates (2017)
1a	Calibration over ocean with no clouds or aerosols	Yes	10/23, 10/25, 11/07
1b	Calibration over land with no clouds or aerosols	Yes	10/25
1c	Calibration over spatially uniform cloud deck	Partially	11/01
1d	Geolocation using coastlines with no clouds	Yes	10/23, 10/25, 10/26, 11/07
1e	Coordinated CALIOP/CALIPSO or CATS underflight	Yes	10/19, 10/26, 11/07, 11/09
2a	Validation with AERONET with medium to high aerosol loading	Yes	10/23, 10/25, 10/26, 11/01, 11/07, 11/09
2b	Validation with AERONET with low aerosol loading	Yes	10/23, 10/25, 10/26, 11/01, 11/07, 11/09
2c	Validation against CASPER field campaign	No	None, but one overlap with an AJAX flight on 11/09
3a	Satellite intercomparison for aerosol retrievals	Yes	10/23, 10/27, 11/01
3b	Satellite intercomparison for cloud retrievals	Partially	11/09
4a	Targets of opportunity: high aerosol loads over ocean	No	-
4b	Target of opportunity: high aerosol loads over land	Yes	10/27, 11/01, 11/07
4c	Targets of opportunity: multiple aerosol layers	No	-

5	Targets of opportunity: aerosol above cloud	No	-
6	Targets of opportunity: high aerosol loads over urban surfaces	No	-
7	Targets of opportunity: marine stratocumulus clouds far from land	No	-
8	Targets of opportunity: broken clouds far from land	No	-
9	Targets of opportunity: low clouds over land	Yes	11/01, 11/03
10	Targets of opportunity: Cirrus clouds	Yes	10/19, 10/23, 11/03, 11/07, 11/09

Table 3 ACEPOL data availability. Archives for the primary ACEPOL instruments (ASDC, AirMSPI and GroundMSPI) contain calibrated Level 1 data with direct physical observations, e.g. radiance, degree of linear polarization, backscatter. Level 2 data are products of retrieval algorithms and include, for example, aerosol intensive and extensive parameters. These may or may not exist in the database(s) depending on the retrieval algorithm maturity.

Archive	URL, DOI
ASDC	https://asdc.larc.nasa.gov/project/ACEPOL_10.5067/SUBORBITAL/ACEPOL2017/DATA001
AirMSPI	https://eosweb.larc.nasa.gov/project/airmspi/airmspi_table 10.5067/AIRCRAFT/AIRMSPI/ACEPOL/RADIANCE/ELLIPSOID_V006 10.5067/AIRCRAFT/AIRMSPI/ACEPOL/RADIANCE/TERRAIN_V006
GroundMSPI	https://eosweb.larc.nasa.gov/project/airmspi/airmspi_table 10.5067/GROUND/GROUNDMSPI/ACEPOL/RADIANCE_v009
AERONET	https://aeronet.gsfc.nasa.gov/
CARB	https://www.arb.ca.gov/adam/index.html

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Table 4 Daily description of ACEPOL flights. Nine flights, with a total of 40.1 flight hours, were carried out between October 19, 2017 and November 9, 2017 for ACEPOL.

Flight Date	Takeoff (UTC)	Duration (hours)	Targets achieved	Instrument status	Coordinated observations	Notes
10/19	16:09	2	1e , CATS: 17:32 10 : 18:00	All instruments functioning	CATS, AERONET	Test flight recalled early due to high winds at landing site. Because of recall, missed potential coordination with CASPER in situ sampling in Central Valley.
10/23	17:01	5.7	1a , late in flight 1d , San Francisco Bay, 19:27 Catalina Island, 21:07 2a , Bakersfield: 17:50, 18:40 2b , Modesto: 19:20 USC_SeaPRISM: 21:07 3a , Terra: 18:40 10 , 19:54-20:26	All instruments functioning	Terra (MODIS & MISR) AERONET, AERONET-OC	Severe clear (few clouds, low aerosol load) flight with satellite coordination. Over flight of ocean AERONET USC SeaPRISM site has ideal geometry for polarimeters, subject of comparison studies.
10/25	16:30	5.9	1a , near coast, 20:49 1b , 5 legs over Rosamond Dry lake: 17:18, 17:50, 18:21, 18:47, 19:24 1d , near coast, 20:49, Salton Sea 21:17 2a CalTech: 18:25, Fresno: 20:15, 2b USC SeaPrism:18:30, Bakersfield: 19:45	All instruments functioning	GroundMSPI at Rosamond Dry Lake (34.85636N, 118.07649W), AERONET, AERONET-OC	Severe clear, primary focus was overflights of Rosamond Dry Lake while a ground team characterized surface reflectance.

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10/26	18:00	4.5	1d , S. California coast: 19:40, Salton Sea: 19:53 1e , CALIPSO underflight: 20:50 2a, Fresno: 18:48 2b, Bakersfield: 19:11	All instruments functioning	CALIPSO, AERONET	Central valley AERONET overflights , followed by CALIPSO track coordination. Cloud free
10/27	17:00	3.2	3a Terra: 18:21 4b Smoke from fires: 18:00, 18:32, 18:55	All instruments functioning, some HSRL gaps (ER-2 cooling problem)	AERONET Terra (MODIS & MISR)	Flight targeting prescribed burns in Arizona. Cloud free.
11/01	16:35	5	1c S. California coast: 17:30 2a Bakersfield: 17:00 2b Flagstaff: 19:20 3a Terra: 18:39 4b Smoke from fires: 19:12 9 Los Angeles basin: 17:45	No HSRL (ER-2 cooling problem), only one AirMSPI target, Reduced AirHARP observations	AERONET Terra (MODIS & MISR)	Marine stratocumulus clouds off S. California, then smoke in Arizona.
11/03	18:58	2.9	9 20:00, 20:42 10 21:10	All instruments functioning		Short flight to test aircraft/instrument repairs. California central valley with multi-layered clouds.
11/07	17:19	5.3	1a 20:31 1d Monterey Bay: 20:16 1e CALIPSO underflight, California Central Valley: 21:18 2a Bakersfield: 17:55, 19:06, 21:57, Fresno: 19:40, Modesto: 20:06 2b CalTech: 18:10 10 18:21, 20:40	AirHARP lost heater, no data for end of flight	CALIPSO, AERONET	Targeting AERONET sites and CALIPSO track, plus clear segment over the ocean.
11/09	17:16	5.6	1e CALIPSO underflight, California and Nevada desert, 21:07 2a Fresno: 22:02 2b Flagstaff: 18:24, 19:55 2c AJAX flight overlap, 21:50 4b Smoke from fires: 19:36, 19:52 10 end of flight	All instruments functioning	CALIPSO, AERONET, AJAX	Return to Arizona for smoke near the Grand Canyon, successfully observed high aerosol loads. CALIPSO under flight, coincident measurement with AJAX flight.

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Figures



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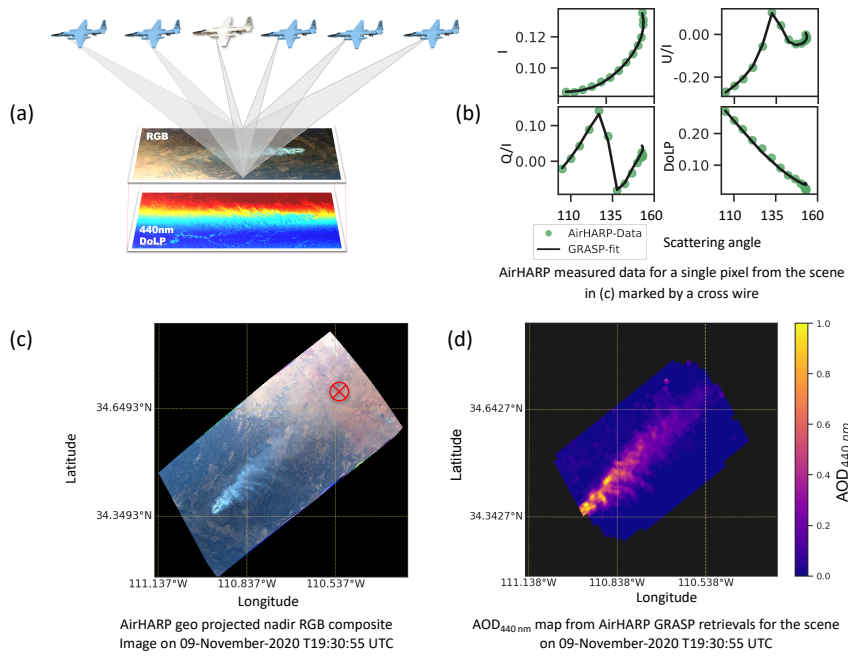
Figure 1 Photograph from the ER-2 of smoke from prescribed burns in Kaibab National Forest in Arizona on November 9th, 2017. Credit: NASA/Stu Broce.



1080 **Figure 2** A portion of the ACEPOL team with the NASA ER-2 at the NASA Armstrong Flight Research Center in Palmdale, California.

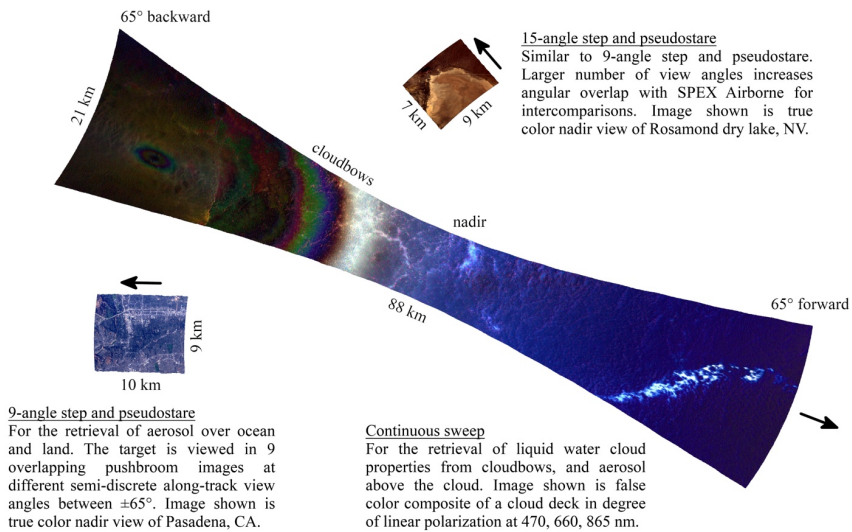


Figure 3 The ACEPOL field campaign emblem, which also shows the positions of instruments onboard the ER-2 aircraft.

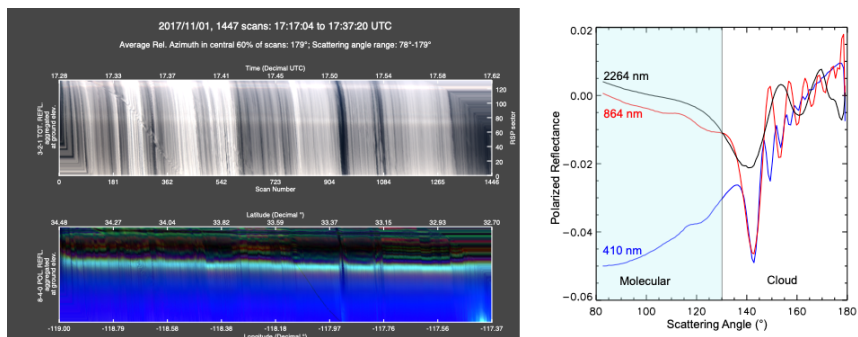


085 Figure 4 (a) Illustration of the AirHARP sampling scheme applied during the ACEPOL experiment. Each along track viewing angle produces a full pushbroom image. Six along track viewing angles are shown in the subplot. HARP has up to 60 along track viewing angles for 670nm and up to 20 viewing angles for other wavelengths; (b) AirHARP measured (solid circles) I , Q/I , U/I and $DoLP$ for a pixel marked by red cross wire in (c), plotted as a function of scattering angle and GRASP forward model fit for the variables of same pixel (solid black lines); (c) RGB composite image of a smoke scene collected on the 9th of November, 2017 at 19:31 UTC; (d) Map of aerosol optical depth (AOD) at 440nm retrieved for the same scene using AirHARP measurements and the GRASP inversion algorithm.

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1095 **Figure 5** AirMSPi quicklooks for the 3 different multi-angle observation modes. Aircraft flight direction is indicated by arrows.



1100 **Figure 6** RSP quick look image (left) from November 1st, 2017. The vertical dimension represents view angle, and the horizontal dimension scan number (time elapsed). At right is a single level IC scan corresponding to scan 1235 at left. It shows the signature of cloud bows at large scattering angles (135 - 180°) and molecular (Rayleigh) scattering for 410 nm at scattering angles smaller than 130° . Retrieved droplet size parameters are effective radius of $11.5 \mu\text{m}$ and effective variance of 0.008 .

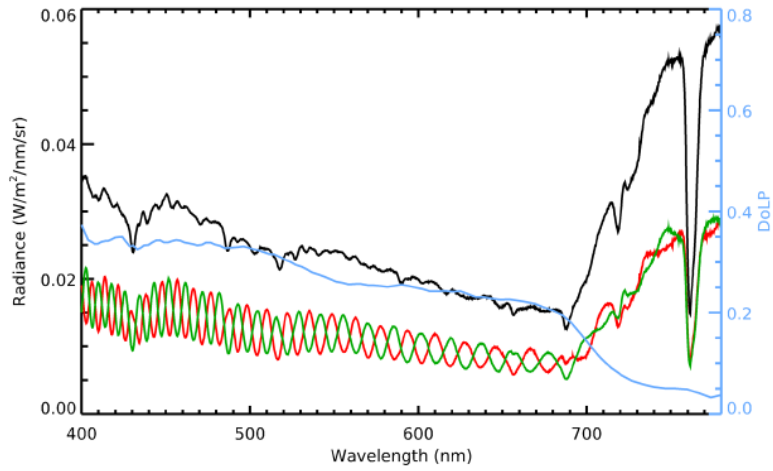
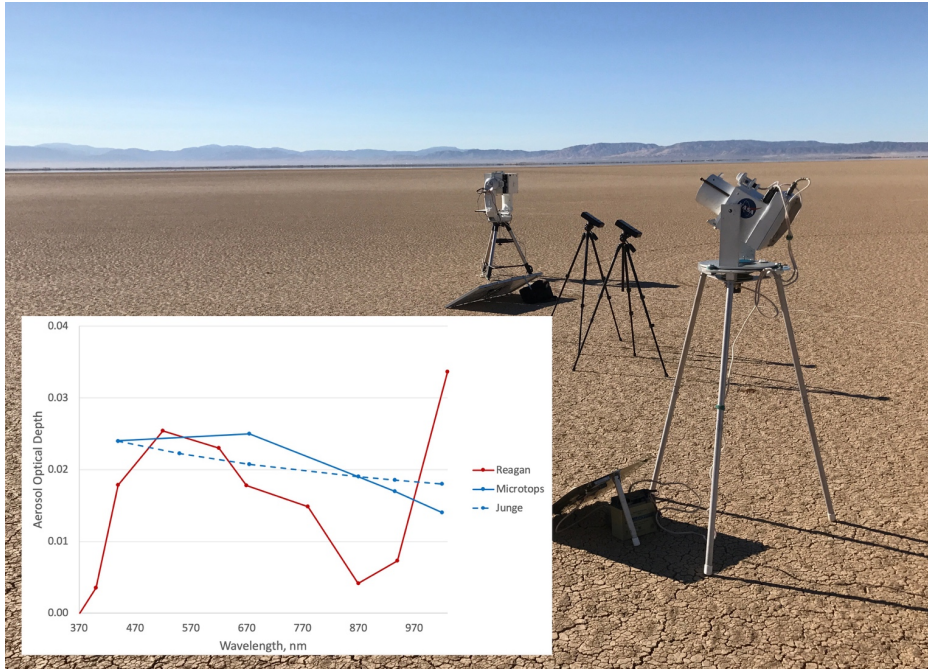


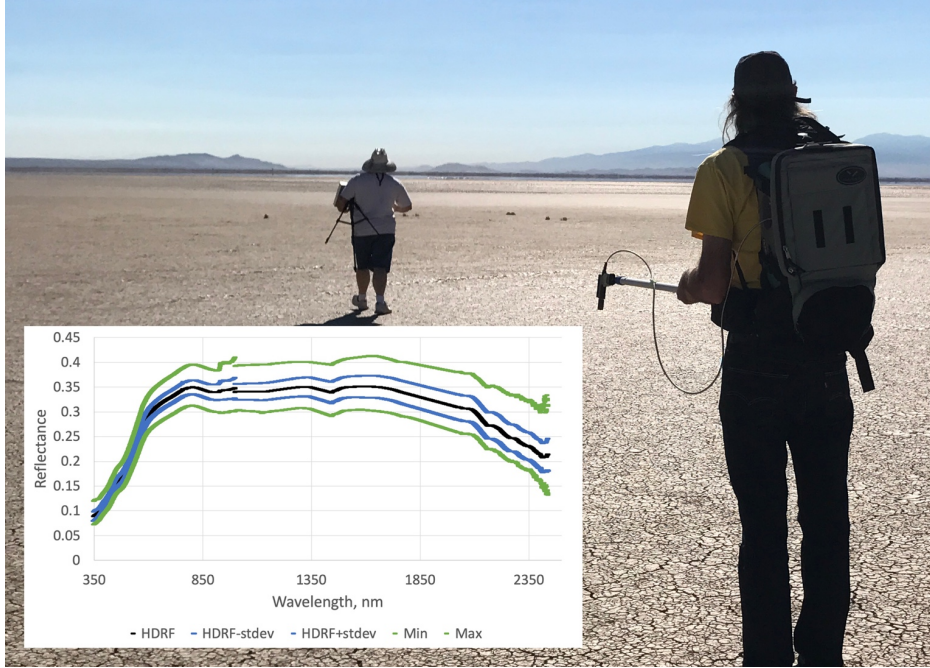
Figure 7 Example of SPEX airborne measurements over vegetation, for radiance (black line) and DoLP (blue line) as function of wavelength. The modulated spectra from which radiance and DoLP are derived are shown in green and red.



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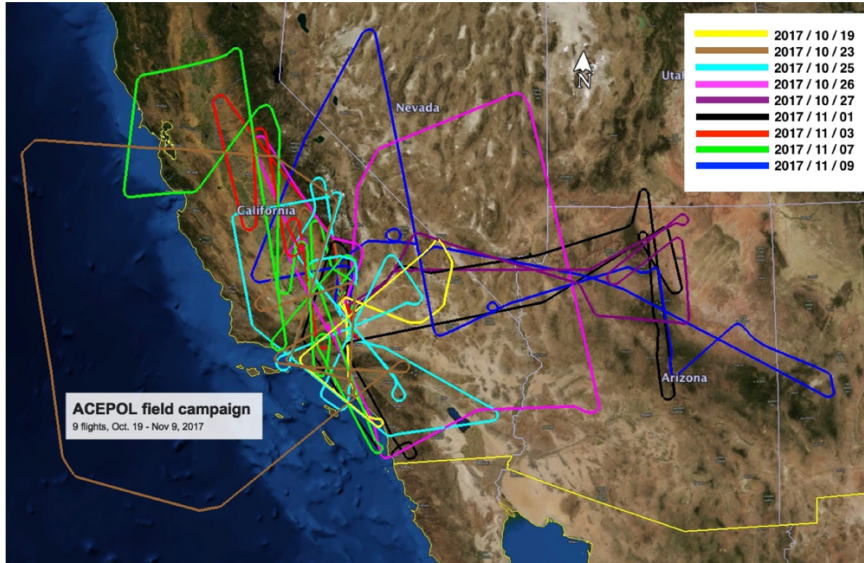
Figure 8 GroundMSPI, two Microtops sunphotometers, and a University of Arizona Reagan sunphotometer deployed on October 25th, 2017 at Rosamond Dry Lake in California. (Inset) AOD as measured by the Microtops and Reagan sunphotometers, plus a Junge model fit to the Microtops data.

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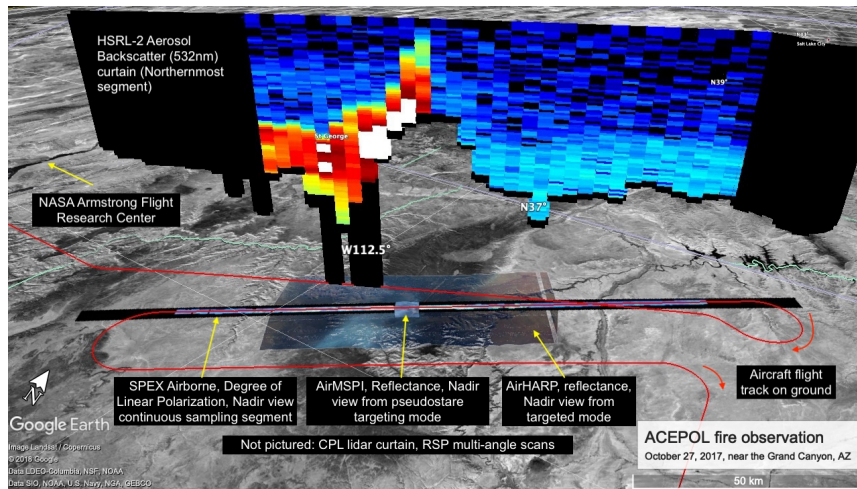


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Figure 9 Surface characterization on October 25th, 2017 at Rosamond Dry Lake in California using a Spectralon reflectance standard and ASD FieldSpecPro. (Inset) Mean and standard deviation of surface reflectance (black, blue lines) with maxima and minima spectra (green). Reflectances are presented in terms of the Hemispherical-Directional Reflectance Factor (HDRF), Schaepman-Strub et al., 2006.



1115 Figure 10 Flight tracks for the ACEPOL field campaign. Nine flights were conducted from October 19th to November 9th, 2017 over California, Nevada, Arizona, New Mexico and the coastal Pacific Ocean from the Armstrong Flight Research Center in Palmdale, California. Image mapped using Google Earth. © 2018 Google.



1120 Figure 11 Example of variable instrument observation characteristics for a scene on October 27, 2017, of biomass burning smoke from prescribed burns near the Grand Canyon. Image mapped using Google Earth, © 2018 Google.