ADVANCED SOUNDER WORKING GROUP REPORT

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This working group focuses on scientific issues affecting the optimal performance of advanced satellite sounder systems. The working group reviews the status of the development of advanced sounder systems and recommends changes pertaining to instrument specification, performance, data processing, and utilisation. For the purpose of this group, "Advanced Sounders" are defined as instruments that present significant new scientific and technological challenges and which require new methods for data processing and utilization. Thus, Advanced Sounders currently include high spectral/spatial resolution infrared and microwave sounders and active sensors.

1. Geostationary Advanced Infrared Sounders

The group recognised the importance of high spectral resolution imaging infrared radiometers on the future global observing system. The development of such instruments on the MTG and FY-4 satellite systems was strongly encouraged and supported. Ideally, these missions should be preceded by, but not dependent on, a demonstration mission. The existing GIFTS instrument is a particularly suitable candidate for such a demonstration mission in the near future.

Recommendation AS-1 to the space agencies:

In reaction to user requirements by the global and regional scale NWP community for more frequent observations of lower tropospheric moisture and temperature profiles, and for additional frequent monitoring of atmospheric dynamics, it is recognised that high spectral resolution imaging radiometers on geostationary platforms would be an important part of the future global observing system. It is therefore strongly recommended that operational missions, like MTG-IRS, be flown as soon as possible. Ideally, a demonstration mission should be conducted for risk reduction purposes, but should not delay the operational missions. GIFTS is the best current option for a demonstration mission.

Action AS-1 on ITWG co-chairs:

Co-ordinate recommendations from this conference with those from the Winds Workshop and communicate to Space Agencies.

IGeoLab

The group continues to support the IGeoLab initiative to promote international cooperation to place and demonstrate advanced sounders (e.g., GIFTS and MW) in geostationary orbit was also noted. A new IGeolab mission has been proposed by Russia, Canada and Finland for 2012. A Molniya orbit is proposed in order to provide many of the benefits of a geostationary platform at high latitudes.

Recommendation AS-2 to the space Agencies

The WMO IGEOLAB concept should be supported.

Recommendation AS-3 to WMO:

GIFTS should be considered as a candidate hyperspectral imager for the IGEOLAB Molniya mission.

2. Calibration and Validation of Advanced Sounder Data

The need for sufficient characterisation, calibration and validation of advanced sounder observations was recognised by the group. The importance of having an SI traceable calibration was emphasised, both for pre- and post-launch phases. The requirements for the parameters that need to be calibrated need to be communicated from the data users to the data providers.

Recommendation AS-4 to data users:

The group encourages pre- and post-launch instrument characterisation and traceable calibration. Requirements for the parameters to be characterised and their required accuracy and stability should be communicated from the users (i.e., NWP, RT modellers, climate researchers) to the data providers.

The important role that NWP centres can have in assisting with the calibration and validation of new satellite instruments, such as IASI, was noted. It is therefore encouraged that data be available to NWP centres as early as possible before the instrument is declared operational.

Recommendation AS-5 to data providers:

To aid in early calibration and characterisation of new instruments data should be released as early as possible to NWP centres.

Field Campaigns

The group noted that a variety of in-situ and complementary data sources are required for full validation of advanced sounders. Direct comparison with high-spectral resolution observations from aircraft under-flights of satellites provide valuable validation of absolute radiances, instrument line shapes, and derived products. Space agencies should provide adequate resources to allow full synergistic calibration activities.

Recommendation AS-6: to the space agencies and NWP centres:

Cal/Val for advanced sounders needs to be an activity which receives sufficient resources. High-altitude airborne sensors, such as those associated with the NAST, S-HIS, and ARIES airborne sensors, and upper air reference networks need to be added to complementary data sources in order to validate the radiances and derived products to the very high accuracy and precision specified by the users. These campaigns should be co-ordinated with new satellite launches.

Recommendation AS-7 to space agencies, NWP centres and researchers:

Case study data sets be prepared and made freely available from these campaigns and the scientific community which is encouraged to use these data to determine instrument and forward model spectral characteristics and to improve retrieval and data assimilation procedures, with a workshop focused on case study applications of the data taking place after a couple of years.

Action AS-2 on Jonathan Taylor:

E-mail details of Joint Airborne IASI Validation Experiment (JAIVEx) data to the ITSC conference.

Experience from IASI Calibration

The Working Group report from the previous meeting recommended that lessons learnt from establishing the in-orbit performance of IASI be used in pre-flight testing of future instruments. IASI underwent very careful ground calibration and the in-flight performance was very similar (if not slightly better). Calibration with different scene temperatures is important. Footprint shape determination, while costly to perform, is much more accurate when done on the ground.

Recommendation AS-8 to Space Agencies:

Future instruments should be carefully calibrated before launch. In particular, care must be taken to accurately establish the instrument field of view, as this procedure is far more accurate when performed on the ground rather than in orbit. (I think this one more specific to the on ground & FOV issues it won't hurt to have it stand along).

Dedicated Satellite for Cross-Calibration

A high accuracy spectrometer, in a low inclination orbit (i.e. $<20^{o}$) would have the ability to cross-calibrate all polar orbiting satellites several times per day as well as geostationary satellites in different longitudinal sectors. These cross-calibrated radiances would be useful in the determination of biases between sensors on different satellite platforms and applying single station *in-situ* calibration to the entire constellation of satellites by linking cross-calibrated radiances with high temporal frequency. This may complement the existing and planned *in-situ* calibration campaigns for many separate satellites if the radiances from several satellites can be cross-calibrated with a single 'standard' satellite.

Recommendation AS-9 to the science community:

The utility of applying the SNO (Simultaneous Nadir Observation) technique for an equatorial (inclination <20°) LEO platform for the purpose of radiometric cross-calibration should be examined. Optimal orbital parameters (attitude and inclination), as well as sensor(s) type, should be determined so that recommendations for possible sensors on future equatorial satellites can be put forward. The CLARREO mission (which is primarily concerned with climate change and is currently planned to be in a 90 degree inclination orbit) partially fulfils these criteria and is a good first step.

Correlated Noise from advanced infrared sounders

Spectrally correlated and spectrally uncorrelated noise component specification is fundamental to satellite observation systems and is a particularly important consideration for the proper use of advanced infrared sounder data. This noise may be intrinsic to the instrument; may be introduced in post-processing; or may be caused by the forward model. Correlated instrument noise are best characterised through both ground-based measurements and in-flight measurements. Spectrally correlated and spectrally uncorrelated noise can be specified in-flight through analyses of calibration data and using Principal Component Analysis (PCA) of Earth scene measurements. Correlated forward model noise (which may include noise due to the effects of spectroscopic errors, cloud, aerosol and surface emissivity not being properly modelled) is best determined through inspection of the observations using the resources of NWP and dedicated validation campaigns.

Recommendation AS-10 to Space Agencies and NWP Centres:

Encourage studies to evaluate the full error covariance matrix of advanced sounder measurements and error introduced by forward models.

Recommendation AS-11 on members of the research community

Use the information from dedicated validation campaigns to better understand the full error covariance matrix of advanced sounder measurements and error introduced by forward models.

3. Objectives and Desirable System Requirements of Advanced Sounders

In order to ensure consistency of objectives and adequacy of the capabilities of various international contributions to the global observing system, the ITWG provides the following guidance on the primary measurement objectives and desirable radiometric measurement requirements to be met or exceeded for advanced IR sounders to be carried on future polar and geostationary orbiting satellites.

Advanced IR Sounder Primary Objectives

Polar Satellite Sounding Observations: The primary measurement objective for polar satellite sounding radiance observations is to infer temperature and water vapour profiles for Numerical Weather Prediction model initialization. The radiance spectra, or the retrieved profile data, to be assimilated need not be spatially contiguous for this and simultaneous microwave observations are generally available to assist in the interpretation of cloudy hyperspectral IR sounding data.

Geostationary Satellite Sounding Observations: The primary measurement objective of geostationary satellite sounding is the observation of lower and upper tropospheric temperature and water vapour dynamics, as needed to enable the nowcasting (i.e. short-term forecasting) of hazardous weather, and the production of water vapour tracer tropospheric wind profiles, used for regional and global NWP. Spatially contiguous, above cloud, sounding observations are needed to observe the atmospheric processes associated with storm systems and for tracing cloud and altitude resolved water vapour motion winds used for NWP.

Table 2.4-1 Measurement Thresholds for Future Advanced IR Sounders

			Polar		**Geostationary**			
Channel cm-1	**δv cm-1**	**Purpose**	**P**	**δS[1] km**	**P**	**δt[2] min**	**δS[3] km**	**Remarks**
660-680	0.6	Strat. Temp.	1	~100	-	-	-	Polar satellite only
680-800	0.6	Trop. Temp	1	15	1	30	≤5	Fundamental Band[4]
800-1000	0.6	T_s, H_2O, Cld	1	15	1	15	≤5	Fundamental Band[5] Cls, Sfc. T/Emis. & H_2O
1000-1100	0.6	O_3	1	15	3	30	~5	O_3, Stratospheric Wind
1100-1590	1.2	T_s, H_2O, Aerosol/Dust	1,2	≤15	2,1	≤15	≤5	Water Vapour Flux Trop. Wind Profiles[6]
1590-2000	1.2	H_2O, T_s, Cld	2,1	≤15	1,2	15	≤5	Water Vapour Flux Trop. Wind Profiles[6]
2000-2200	0.6	CO, T_s, Cld	3	15	2	60	~5	Trace Gas/Air Quality
2200-2250	2.5	Trop. Temp	2	15	2	15	~5	Clear Ocean Day and Land/Ocean Night Utility[8]
2250-2390	2.5	Strat. Temp.	4	100	-	-	-	Night-time Utility[8]
2386-2400	2.5[9]	Trop. Temp	4	15	-	-	-	Night-time Utility[8]
2400-2700	2.5[10]	T_s, Cloud	3	≤15	-	-	-	Clear Ocean & Night Land Utility[8]

Table definitions: channel (spectral coverage), **δv** (spectral resolution, unapodized for the case of an FTS, assuming an instrument self apodization of less than 5%), P (priority), δt (refresh rate), δS (footprint linear resolution).

The values given are the threshold requirements with objectives being better by as much as practical from a technology and cost point of view. Priority 1 measurements are required to fulfil advanced sounding primary objectives.

[1] For cloud clearing, the highest spatial resolution is desired
[2] Refresh rate for regional (3000 km x 3000 km) area coverage at full spectral resolution as desired for convective storm applications of the data (i.e., thermodynamic stability and water vapour flux measurement). Broader area coverage (e.g., 9000 km x 9000 km), with 30 to 60 minute refresh rates, is desired for temperature, moisture, and wind profile measurements for NWP applications, but these can be performed at lower spectral resolution (e.g., 2 x □□).
Spatial contiguity is required to observe atmospheric dynamical processes
This band is fundamental for day/night high vertical resolution temperature profiles required for determining atmospheric constituent profile and cloud parameters from hyperspectral radiance emission measurements
High spectral resolution is needed to resolve on-line/off-line radiance determinations of surface reflectance/emissivity and to separate water vapour/cloud/dust contributions
High spectral resolution provides shortwave window observations, near the edges of these bands, as needed for cloud clearing. Either longwave (1100-1590 cm^{-1}) or shortwave (i.e., 1590-2000 cm^{-1}) sides of water vapour band can be priority 1. Having measurements covering both longwave and shortwave sides of the water vapour band will optimize the water vapour profile accuracy throughout the atmospheric column. Thus, if one side is chosen as Priority 1 then the other side becomes a Priority 2.
Spectral resolution resolves CO lines and provides shortwave window observations near 2000 cm^{-1} desired for cloud clearing, surface temperature, and cloud property estimation.
Reflected sunlight complicates the daytime utility of these data for cloudy sky and/or land surface conditions.
A spectral resolution of 0.05 cm^{-1} is desired to resolve the contribution from in-between the absorption lines.
The AIRS 2616 cm^{-1} channel, with 2.5 cm^{-1} resolution, has been found useful for cloud detection and sea surface temperature measurement.

Action AS-3 on Bill Smith:

> Review and re-create this table with particular emphasis on establishing a link between instrument and geophysical measurement criteria (particularly WMO requirements).

Recommendation AS-12 to the space agencies:

> In order to ensure consistency of objectives and adequacy of the capabilities of various international contributions to the global observing system, it is recommended that space agencies follow the ITWG guidance on desirable radiometric measurement requirements to be met or exceeded for advanced IR sounders to be carried on future polar and geostationary orbiting satellites.

Advanced Microwave Sounder Objectives

(I think, for now, MW imager is not in AS WG radar screen. Same is true for IR imager). If it's useful we can further expand AS WG to include non-sounder instruments and change the name to advanced sensor. This issue can be up for discussion in ITSC-17.

At ITSC-XIV, it was recommended that studies be conducted to identify the requirements for future microwave sounders, both for polar and geostationary orbits. These studies are still required.

Recommendation AS-13 to the research community and space agencies:

It is recommended that relevant organizations conduct studies to identify the capabilities of microwave sounders and develop consensus user measurement requirements for future systems. This should be done for LEO as well as GEO. It is recommended that this information be consolidated in a table similar to that presented above for the IR sounder.

Action AS-4 on Bjorn Lambrigsten and Bill Blackwell:

Prepare a draft table summarising the requirements for microwave sounding systems between instrument and geophysical measurement criteria (particularly WMO requirements). This should be communicated to the frequency-protection community.

Action AS-5 on the Advanced Sounders Working Group:

Review the tables produced by Actions AS-3 and AS-4.

3. Configuration of Future Systems

Advanced Sounder Field-of-View Size and sampling interval

It was noted that the current field-of-view size for advanced infrared sounders are larger than optimal to avoid cloud contamination. It is further noted that the optimal requirement for sounder fields-of-view size and sampling interval may evolve with future advances in sounding techniques for cloudy regions.

Recommendation AS-14 to the scientific community:

Further studies on optimisation of the size of advanced sounder fields-of-view and spatial contiguity need to be pursued, taking into account probable future advances in sounding techniques.

CrIS Spectral Performance

It was noted that the performance of CrIS will be inferior to IASI both in terms of spectral resolution and spectral coverage.

High spectral resolution is important for obtaining high vertical resolution retrievals and for resolving spectral features of many trace gas species. The spectrum as measured by the CrIS instrument itself is of similar resolution to IASI, but the interferograms for the midwave and shortwave bands are truncated before being communicated to Earth - resulting in the degraded

performance noted above. The group therefore encourages the full CrIS interferogram to be transmitted to Earth and for the CrIS measurements to be communicated to users with their full spectral information content for all three of its measurement spectral bands.

Unlike IASI, CrIS does not have contiguous spectral coverage but has gaps in the 8μm window and the shortwave side of the 6.3μm H_2O band. The latter region has already been shown to provide CO information from IASI and is also a source of information for near-surface humidity, N_2O and isotopic H_2O information. The group therefore recommends that further investigations be undertaken into the possibility of communicating the full CrIS spectrum.

Recommendation AS-15 to IPO:

CrIS measurements should be communicated from the satellite at full (as measured) spectral resolution.

Recommendation AS-16 to IPO:

Further investigate communication of the full (as measured) CrIS full spectrum.

On the performance of Conically-Scanning Microwave Instruments

The group noted that recent studies have inferred that the impact of the DMSP SSMIS conically scanning microwave sounders is i at present less than that of the cross track sounders, the difference arising from the impact of solar intrusions (direct and reflected) onto the calibration blackbody. It was reported that these problems have been resolved for the DMSP F-18 SSMIS. The group therefore recommended that the performance of future conical sounders be reviewed after F-18 SSMIS data becomes available

Recommendation AS-17 further study to Space Agencies/IPO:

Further study the ability of conical sounders, using on-orbit data from new conical imager/sounders as it becomes available as well as data from existing sensors, to deliver sufficiently accurate observations for NWP in the light of the most recent results.

Recommendation AS-18 further study to Space Agencies/IPO:

Future conical sounding missions should take full account of the experience gained in the post-launch analyses of existing operational conical imagers and sounders (including SSMIS, Windsat, TMI and AMSR) in the specification and design of instruments.

MW Sounder Deployment with Future IR Sounders

It is desirable to fly microwave sounders with future IR sounders configured in such a way as to enable simultaneous observations (i.e. collocated in space and time). Cloud-clearing will be enhanced and sub-cloud level information will be provided for spatial and temporal continuity. Such MW observations

are desired to be obtained together with the observations from future advanced IR sounders.

Recommendation AS-19 to the space agencies:

Microwave sounders should be considered to always be flown with future advanced IR sounders, to provide simultaneous observations at the same time and at the same location.

Imagers with Sounding Channels to Support Future IR Sounders

High spatial resolution imaging radiometers which possess one, or more, lower tropospheric IR sounding channels (e.g., MODIS) provide valuable data for cloud-clearing and for the quality control of cloud-cleared radiances from advanced IR sounding instruments. Furthermore, for the case of complex partly cloudy scenes, where cloud clearing is unsuccessful, the imager sounding channel radiances provide valuable information for filling gaps in advanced sounder information otherwise lost below clouds. It is desirable that imaging radiometers fly with future IR sounders and that they possess sounding channels in addition to their "window" channels.

Recommendation AS-20 to the space agencies:

Future high spatial resolution imaging radiometers to be flown with advanced IR sounding instruments should possess channels primarily sensitive to lower tropospheric emission to support the interpretation and enhance the use of advanced IR sounding spectrometer observations obtained for cloudy sky scene conditions.

Spacing of satellites when during MetOp overlap periods.

MetOp-A and -B will be flying in parallel with the same equator-crossing time for up to five years after the launch of MetOp-B. As they will be using the same ground-based antenna their orbits need to be separated by a minimum of 20 minutes and a maximum of 50 minutes. The desirable separation between the satellites for the joint use of the data for specifying atmospheric dynamics (e.g., altitude resolved moisture tracked wind profiles, stability tendencies, etc.) should be determined by the NWP centres.

Recommendation AS-21 to EUMETSAT: All MetOp level-1 and level-2 data should be distributed in near-real time from both satellites.

Recommendation AS-22 to NWP centres: Preferences for separation between the two satellite should be communicated to EUMETSAT.

Recommendation AS-23 to ITSC: Investigate the implications on developing innovative products from two METOP satellites with 20-50 minute separation. I agree.

On the continuation of the global GPSRO constellation

GPS radio occultation (GPS RO) observations are currently assimilated at a number of NWP centres. These measurements provide an important "anchor" for the bias correction of satellite radiance measurements as they are assimilated without bias correction and the active use of such data is important for NWP systems with adaptive bias correction schemes. The only dedicated GPS RO constellation (as opposed to individual satellites) is the six-satellite COSMIC mission, which is due to end in 2011. A fully operational follow-on to this mission is desirable.

Recommendation AS-24 to Space Agencies:

A fully operational constellation of GPS radio-occultation receivers provides useful calibration information for satellite sounders and thus the group recommends a follow-on from the current COSMIC constellation to be flown.

Optimal use of community state-of-art algorithms and systems within prime contractor operational processing for satellite programs

Environmental satellite systems have historically been developed by a partnership of government (NASA, NOAA, and EUMETSAT, for example), industry and university science communities. While the technological expertise of industry is a key part of the entire system, industry is not well-suited to supplying the broad perspective on the use of these future systems nor is it well suited to developing the necessary pre-launch simulations, ground data processing science algorithms, and associated data application approaches. The ITWG believes that approaches, which require prime contractors to implement operational systems without making full use of community advances in algorithm and data processing system development, decrease overall quality and usage of final data products and increase program risk.

This includes activities associated with pre-launch instrument simulations, proxy data generation, and processing algorithm development and testing, through post-launch infusion of algorithm advancements to enhance operational processing data product quality and utility.

Not ensuring infusion of latest community advancements also inhibits the science community from acting as an objective, commercially-neutral, body in the development and implementation of future satellite systems.

Recommendation AS-25 to Space Agencies:

Environmental satellite systems should be developed by a partnership of government, industry and university science communities under the leadership and responsibility of government agencies.

4. Exploitation of Advance Sounder Data.

Distribution and Optimal Use of Advanced Sounder Radiance Data in NWP.

The current use of advanced sounder data in NWP is very conservative. The limitations are the cost of radiative transfer modelling and the transfer of large observation datasets from the satellite agencies to the NWP centres. Full use of these data requires the efficient use of all the information in a compressed form. Candidates include Principal Component (PC), reconstructed radiances, and retrievals. Investigations with reconstructed radiances are in progress, as they are most similar to the data already being assimilated. It was recognised that the use of principal components and retrievals would present much larger scientific and technical challenges to the NWP community. In choosing the optimal strategy to use, consideration must be given to the specification of the observation error covariance matrix, averaging kernels, quality control, cloud detection and monitoring.

Recommendation AS-26 to NWP Centres:

It is recognised that more efficient use of the full advanced IR sounder spectrum is desirable within NWP data assimilation. NWP centres are encouraged to consider research into the direct use of principal components and/or retrievals from advanced IR sounders in assimilation systems.

Recommendation AS-27 to retrieval providers:

Provide full characterisation of retrieval schemes including observation error covariance matrix, averaging kernels, quality control, and cloud detection. This characterisation should be both theoretically derived and independently validated. Data should be available in suitable and timely format.

Recommendation AS-28 to the ITSC:

Where possible, retrieval studies should be presented with averaging kernel and full error covariance estimates and validation.

It was noted that the use of principal components to compress advanced sounder data is fundamentally a lossy technique. For many applications the small amount of lost information may be acceptable, but it can be problematic when the principal components have been generated in such a way that the desired signals are not present. For this reason, care must be taken that for general archiving of data, the compression scheme should be lossless. Datasets with lossy compression can be distributed if they are identified as such.

Recommendation AS-29 to data providers:

It is noted that the use of principal components to represent advanced sounder spectra carries the danger of the loss of signals that are not properly represented in the training set. Care must be taken to ensure that data compression methods used for archiving of satellite data be lossless. Lossy compression of advanced sounder data for transmission may be acceptable for certain users. This question has become particularly pertinent in the context of continued distribution of IASI data in near real time.

Action AS-6 on Ken Holmlund and the ASWG co-chairs:

Produce a table documenting the timeliness required (i.e., type of distribution) and the required fidelity of advanced sounder data as a function of user type (e.g., NWP, trace gas retrieval, climate applications) as a guide to space agencies on the most efficient strategy for data dissemination.

Action AS-7 on ASWG and other working groups:

Critically review the table produced by AS-6.

It was noted that most discussion about compression of advanced sounder data concentrated on compression in the spectral domain. Simple methods of reduction of data volume by thinning are already in use (e.g., the dissemination of the warmest field-of-view in the AIRS footprint). It was suggested that more sophisticated methods for spatial compression may be possible, particularly for the case of hyperspectral imagers.

Recommendation AS-30 to researchers:

Consider possibilities for spatial compression at the data source.

It was also noted that research into truly lossless compression techniques continues in the wider scientific community. It is recommended that space agencies investigate whether state-of-the-art lossless data compression techniques may be used to aid dissemination of advanced sounder observations.

Recommendation AS-31 to Space Agencies:

Encourage further investigation of truly lossless data compression techniques.

Infrared Surface Emissivity

The accurate determination of the spectrum of land surface infrared emissivity is crucial to the determination of the near-surface atmospheric state from these data. Derivation of the land surface emissivity relies on the combination of a realistic first guess and an accurate retrieval algorithm. The presence of cloud in the field of view can affect the accuracy of the emissivity retrieval algorithm.

Recommendation AS-32 to the research community:

Continue work on infrared land surface emissivity databases including validation and intercomparison between techniques.

Recommendation AS-33 to the research community:

Continue work on infrared land surface emissivity retrieval algorithms including validation, intercomparison between techniques and investigation of robustness to cloud in the instrument field-of-view.

Recommendation AS-34 to the research community:

Databases of global infrared land surface emissivities should be represented in spectral resolution fine enough to resolve spectral feature of earth surface. The use of EOF as an efficient way to model the spectral databases is encouraged but further verification study is recommended.

5. Interaction with Other Bodies

The working group noted the upcoming 4th Hyperspectral Workshop to be held at EUMETSAT, Darmstadt, Germany on 15th-17th September 2008. As there are now two major conferences, at least, devoted to hyperspectral sounding - the Hyperspectral Workshop and the IASI conference - in addition to the Advanced Sounders Working Group, it was suggested that there be co-ordination between the organisers of these to ensure that the most important topics are discussed.

Recommendation AS-35 to the relevant chairpersons:

It is recommended that there be co-ordination between the Advanced Sounders Working Group, the Hyperspectral Workshop, the IASI Conference and the AIRS science team.

Action AS-8 on the Advanced Sounder Working Group co-chairs:

Co-ordinate with the IASI conference chairs, the AIRS science team and Paolo Antonelli to suggest possible topics that should be covered at future workshops and conferences.