Nauticam's WACP

Wide Angle Corrector Port

By Alex Mustard

As I settle down to write this, Nikon have released the new D850 with 46MP and according to my Facebook feed, scores of my friends have found their new camera and are busy emailing manufacturers telling them they need the housing now, or ideally yesterday.

Nikon, Canon and Sony all now offer full frame still cameras that exceed 40 megapixels and for our video shooting brethren, the message from their manufacturers is that you are wasting your time pressing record if it is only 4K, even more resolution is clearly the future! And while those with older cameras might chuckle at this pixel chasing, I think we'd all like our best shots to be captured at the optimum quality, in the highest possible resolution.

A consequence of ever increasing resolutions is photographers can look deeper into the detail of their images than ever before. And we don't always like what we see. As a result, we've all become a pickier about image quality, not only compared to when we squinted through a loupe on a Lightbox, but also compared with digital cameras of just a few years ago. It's understandable that when we've invested in the latest and greatest camera we want to extract its full performance underwater.

There's an old saying in underwater photography that if you want better pictures, don't buy a better camera, but spend your money on diving in better water! But jokes aside, as long as we are close to the subject, as good photographers invariably are, the problem is rarely the water, but the optical problems of shooting underwater. Therefore, the biggest bottleneck to image quality is not the water itself, but the barrier between the air inside the housing and the water beyond (and what shooting through this does to the image quality.)

Nauticam's new WACP will be released soon. Its arrival makes us question where the real bottleneck in achieving the best quality images underwater lies.

Red Sea scenery, June 2017. Nikon D5 and Nikon 28-70mm @ 28mm. Subal ND5 housing. Nauticam WACP. Seacam 150 strobes. 1/160th @ f/18, ISO 640.

A dome port is the typical solution in wide angle photography. Domes have many pluses, but by making the air-water interface curved they introduce some serious degradation to our image quality. The most common manifestation, that we are all familiar with, is the blurring of detail in the corners of wide angle photos. This problem is most prevalent on full frame cameras, with small dome ports, incorrectly positioned dome ports, at more open apertures and with rectilinear, rather than fisheye, lenses.

It is this problem that Nauticam is addressing with their new Wide Angle Corrector Port, which uses fully corrected water contact optics to tackle the limitations of a dome port. The aim is to create a wide angle zoom, with a maximum field of view (FOV) of 130˚, which is wider than either the Canon 11-24mm (126˚ FOV) or Nikon 14-24mm (114˚ FOV), that also produces excellent underwater image quality across the frame, even at more open apertures.

What is the WACP?

The WACP is a lens and a port all in one. It is designed to be used in front of a standard land lens (up to 28mm on full frame, which provides the autofocus, exposure control etc.), while the WACP corrects the lens to see perfectly underwater and expands it into a wide angle with a field of view to 130˚, introducing some mild barrel (fisheye) distortion. To perform this transformation the WACP contains multiple elements of high quality optical glass – about 3 kg worth or well over 6 lb, all there to deliver excellent image quality underwater.

If you are familiar with Nauticam's WWL-1 lens, you can think of the WACP as the pro version, intended expressly for full frame stills and high-end cinematography. Like the WWL-1, the WACP is designed to work with lenses with a field of view up to 75˚ (14mm on M43 or 28mm on FF). This gives plenty of options for full frame photographers, including 28mm prime lenses and zooms, such as the 28-70mm. However, lenses with really large front elements don't work well with the WACP, and physically smaller lenses actually give the better results. Nauticam initially favored Nikon 28mm primes (f/1.8 and f/2.8) in their tests, while in the field, I favored the versatility of a 28-70mm (f/3.5-f/4.5), which becomes a 130˚ to 57˚ FOV lens (for comparison the Canon 11-24mm is 126˚ to 84˚ FOV and Nikon & Canon 16-35mm are 107˚ to 63˚ FOV).

So far the testing has been Nikon biased, but the WACP is not restricted to any brand of camera or specific lenses. Also, like the popular SMC, there is no reason that the WACP can't be used with any housing brand (with an appropriate adaptor).

Nauticam's WACP is port and a lens, that is designed specifically to work underwater, greatly improving image quality compared with dome ports. Used with the 28-70mm zoom it also offers unrivaled versatility in FOV, from 130˚ to 57˚. Nassau grouper in Cuba, August 2017. Nikon D5 and Nikon 28-70mm @ 60mm. Subal ND5 housing. Nauticam WACP. Seacam 150 strobes. 1/100th @ f/12, ISO 640.

At 130˚ FOV the WACP is wide enough for most subjects. Top, Kittiwake in Grand Cayman. Bottom, Chrisoula K in Egypt. Both Nikon D5 and Nikon 28-70mm @ 28mm. Subal ND5 housing. Nauticam WACP.

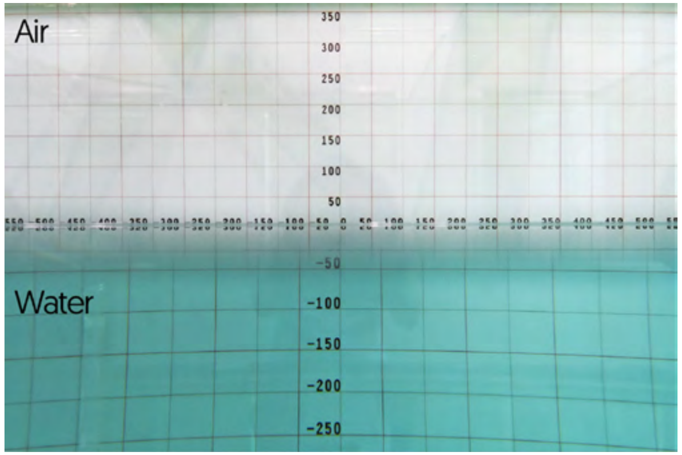
Why use water contact optics?

The short answer is that these are lenses designed to work in water, rather than in air. All the big optical problems of ports (that main bottleneck in underwater wide angle image quality) occur because of the air to water interface. Water contact optics properly correct for this interface and therefore image quality rockets up.

For us to understand it fully, and to appreciate why Nauticam have put so much hard work into designing this lens we need to examine why we use domes ports, their strengths and their weaknesses, because the reason for using water contact optics is to overcome these weaknesses.

Before the 1960s, all underwater photos were taken through flat windows, the port hole in the housing (this is where the word "ports" comes from). We still use them with longer focal length macro lenses where their optical shortcomings are not a big problem. All flat ports suffer from strong refraction when light passes through the flat water/air interface at an angle. The greater this angle (i.e. the wider the lens sees) the worse the problems become. The main optical problems of a flat port in water are a FOV reduction by about 33%, pincushion distortion, blurring of detail and color fringing — all of which get worse and worse towards the corners.

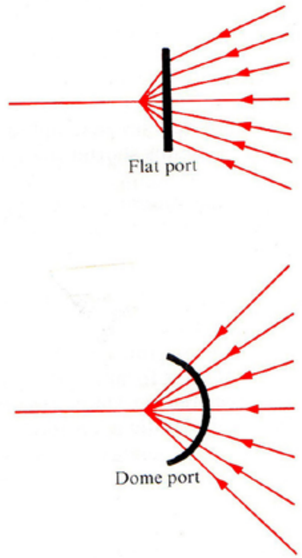
It is worth noting that when light passes straight through a flat port (i.e. at 90˚ to the water/air interface) there is no refraction and no problems. This is actually how dome ports solve all the problems of flat ports. The spherical shape of the port means that as the lens sees wider and wider, it still encounters a port that is at 90˚, so the light passes through un-refracted. This is why dome port positioning (i.e. your port extension length) is critically important.



A photo (half in the water, half out) taken through a flat port with a 24 mm lens on full frame (by Edward Lai). The flat port in air has no impact on image quality. But once submerged, the water/air interface reduces FOV by about 33% (magnifying the squares by the same amount), creates pincushion distortion (lines bend) and other optical problems not really visible until you zoom in (lines are more blurred). Note that all the problems get worse towards the corners, where the refraction is greatest.

The first record of a dome port being used underwater was by the French Navy in 1931. The first underwater photographers to publicize the use of dome ports were Flip Schulke and Walter Starck in around 1963/4 (both of them also shooting the first split level shots to show the angle of coverage of the lens remained the same.)

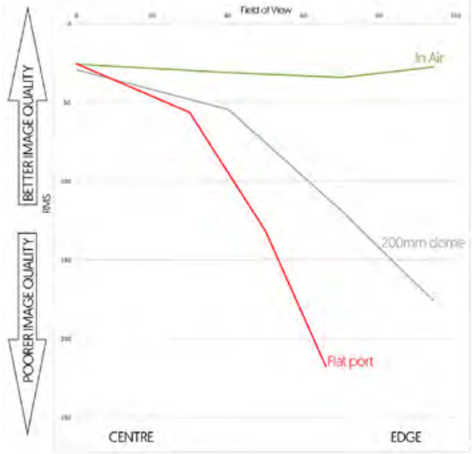
As most underwater photographers know, dome ports are great, but not perfect. The most noticeable downside of the curved water/air interface is that it acts as a simple negative lens and creates a virtual image of the subject. The virtual image is much closer to the port than the real subject (not that big of a deal) and curved in parallel with the port (a significant problem). We must focus on this virtual image to have the subject in focus, but lenses are designed to focus on flat images and because the virtual image curves more towards the edges of the frame, detail becomes increasingly out of focus, or blurred. This is the primary cause of soft corners when shooting with a dome.



Refraction With Flat And Dome Ports – Reproduced from De Couet & Green (1989) "With a flat port, light rays entering the housing are increasingly refracted away from the perpendicular, the larger the angle they form with the optical axis. This leads not only to a reduction of the angle of view but also to severe pincushion distortion of the image. With a dome port, all light rays entering the lens pass through the port at right angles and are therefore not refracted."

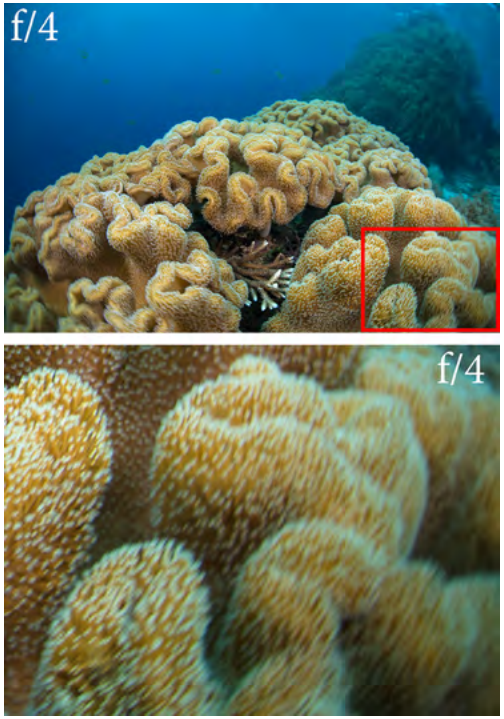
As an important aside, the key to overcoming blurred corners with a dome is to close the aperture hence increasing the depth of field and getting more of the curved virtual image in focus. A correctly positioned dome port is also important. If the lens is too close to the dome (a common problem) then the port acts more like a flat port and problems of refraction degrade image quality. Bigger domes also help. A large dome creates a virtual image that is further from the lens and less curved than a small dome, which reduces the blurriness of corners.

The graph shows image quality data from optical spot diagram simulations (using Zeemax software) at four points across the frame with a wide angle lens. The three lines represent the lens in air (green), in water behind a 200 mm dome (8”) (grey), and in water behind a flat port (red). In air the horizontal line shows that the lens maintains good image quality from the center to the edge of the frame. With the flat port, the image quality falls rapidly as the FOV increases, caused by the increasing refraction and the problems it brings. The dome port improves on the flat port, but image quality also drops away towards the edge of the frame because of the field curvature and other image aberrations. Before you sling your ports, remember that these tests are done with open apertures, so are a worse case scenario, especially for the dome.

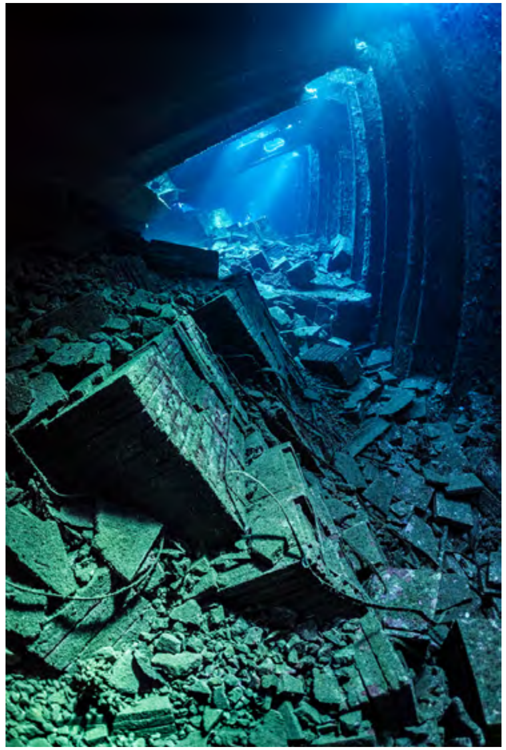


The impact on image quality of a dome port and a flat port compared with a lens in air (this graph plots RMS GEO radius against the FOV of a lens, data source: Zemax spot diagram analysis, Edward Lai, 2017). Results are discussed in the text.

The take home messages are that ports are not perfect and the wider the lens sees, the harder it is to get good image quality into the corners of the frame. When using wider angle lenses, flat ports degrade image quality more than domes. Lenses with a FOV of more than 35˚ will show significant loss in quality towards the edge of the frame with a flat port. The popular 60 mm macro has a FOV of 40˚ on full frame and even this relatively long focal length lens shows issues in the corners of the frame (when detail is present), with loss of resolution and enhanced chromatic aberration. Be aware of this limitation when using lenses wider than a 60 mm with a flat port. While dome ports are better than flat ports, they still drop a lot of image quality towards the edge of the frame compared with the lens in air because of field curvature and other optical problems.



A wide angle photo taken with an aperture of f/4 to show classic corner blurring with a dome port. The area in the red box on the upper image, is enlarged in the lower image, showing the loss of detail.



A water corrected lens does not suffer the problems of field curvature of a dome port, that we usually use a closed aperture to overcome. As a result we can shoot at much wider apertures when we need to in low light conditions and still achieve acceptable corner detail. Available light inside a wreck, Egypt, July 2017. Nikon D5 and Nikon 28-70mm @ 28mm. Subal ND5 housing. Nauticam WACP. No strobes. 1/15th @ f/5.6, ISO 2000.

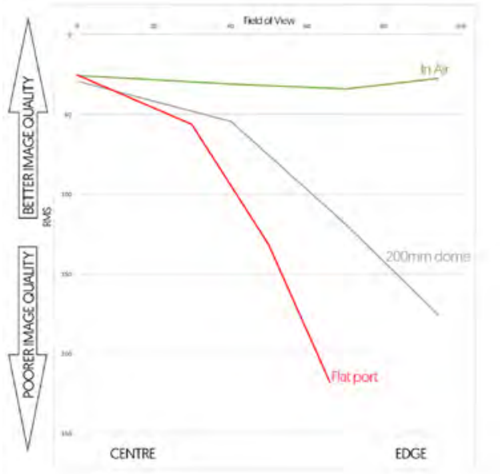
Fully corrected water contact optics overcome field curvature and the other optical problems of domes at all apertures, lifting the image quality much closer to how lenses perform on land.

Dome size and position

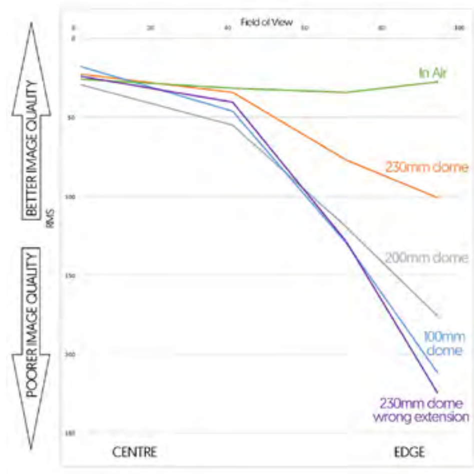
Before moving on, I want to add more data to the graph from the previous section, which is very valuable for improving our understanding of using dome ports. As far as I know, this is the first time anyone has probably collected and certainly presented test data of this kind for different domes.

The 100mm (4”) dome port performs slightly worse than the 200mm (8”), while the 230 mm (9”) performs considerably better. However, do note the data for a 230 mm dome that was not placed correctly, using a port extension just 3.8cm or 1.5” too short — something I see lots of people doing. Like this, the expensive 230 mm dome now drops as much image quality at the 100 mm. The graph shows that big, expensive domes deliver on image quality, however, they must be correctly positioned to do so. (Also note that all domes give good sharpness in the center of the picture, the advantage of bigger domes comes towards the edge of the frame.)

At this stage, perhaps the most



The impact on image quality across the frame when using different sized dome ports compared with a lens in air (this graph plots RMS GEO radius against FOV of a lens, data source: Zeemax spot diagram analysis, Edward Lai, 2017). Results are discussed in the text.



The impact on image quality across the frame when using different sized dome ports compared with a lens in air (this graph plots RMS GEO radius against FOV of a lens, data source: Zeemax spot diagram analysis, Edward Lai, 2017). Results are discussed in the text.

important message is don’t panic. Just because your dome doesn’t achieve the theoretically perfect image quality, it won’t stop it or you taking nice pictures. It still works just as domes always have, which after all have been used to take almost every amazing underwater wide angle you’ve ever seen! And I should stress again that these tests use an open aperture and closing it reduces the problems of field curvature increases the image quality a dome produces considerably.

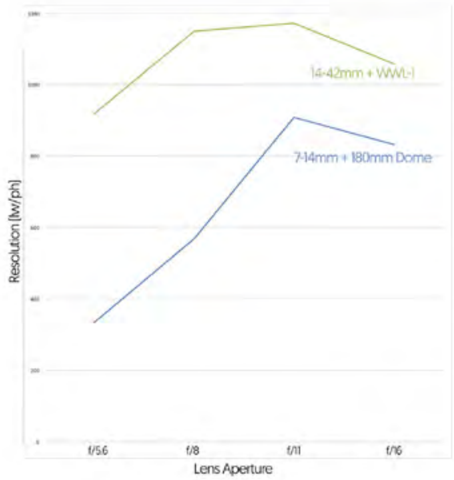
How much difference do water contact optics make?

The answer to this is it depends if they are good or not! Water contact optics have the potential to significantly outperform domes as Nikon showed with legendary lenses like the Nikonos 15 mm and Nikonos RS 13 mm. However, lenses are not easy to design and to be honest, the majority of lenses and ports that have been marketed as water contact down the years are not fully corrected and don’t outperform a correctly positioned dome. Caveat emptor.

https://vimeo.com/144083763

For me, the Nauticam WWL-1 was a game changer in this regard and it is what started me haranguing Nauticam for an SLR version after my buddy Peter Rowlands took one of the first WWL-1s on our trip to California two years ago. Seeing the image quality of Peter’s dailies, first hand, made me want to use this technology on my camera.

The WWL-1 is a wide angle wet lens, intended for Mirrorless and Compact cameras. Think of it as a little brother to the WACP! It is designed to work with a standard zoom behind a flat port and to convert this into a wide angle. In fact, not only is the front element corrected for being in water, so is the rear, and it also corrects for the problems introduced because the camera’s lens is looking out through a flat port immersed in water. As I mentioned above, not all wet lenses are created equal!

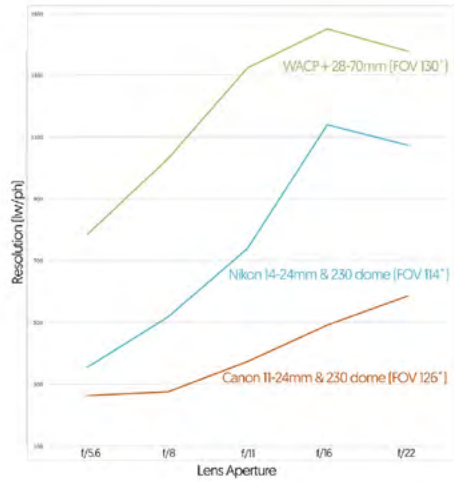


The graph, above, presents real data measured underwater in Nauticam's optical testing facility (note that the axis are totally different to the previous graphs). The graph shows the amount of detail resolved by the camera close to the corner of the frame, across a range of apertures. The data is from a M43 camera with two different lens setups – Nauticam's 180 dome and 7-14mm wide angle (the lens costs $1300, dome $500, seeing 114°) and a 14-42mm kit lens (which costs just $300) and the Nauticam WWL-1 (which costs $1150, seeing 130°).

Look at the 7-14mm and dome first, because the line reveals the classic problem of dome ports and the solution. At open apertures the resolution is low because of field curvature causes blurry corners, but closing the aperture helps considerably by bringing more of the virtual image into focus and therefore increasing the amount of detail resolved, peaking here at f/11. There is a small drop off in detail captured at f/16 because of diffraction (this is a 2x crop camera, on a full frame camera we could expect this line to be shifted a stop or so to the right because diffraction will come later).

The most obvious feature of the WWL-1 data is that despite giving a wider view (130° vs 114°) it resolves more corner detail across the entire aperture range than the 7-14mm and dome do when performing at their best. Secondly, the WWL-1 data form a more horizontal line, with a lower loss of corner detail at more open apertures. This occurs because the water contact optics of the WWL-1 don't have the same problems of field curvature as a dome. An important and perhaps surprising message here is that despite using a cheaper "kit" land lens, the superior correction provided by the WWL-1 results in significantly better underwater image quality than the expensive wide angle lens when used behind a dome.

Moving on to the big brother, the WACP has a major advantage over the WWL-1 – that it is not a removable wet lens, so corrections only have to be made at the front surface (not for the rear surface or the troublesome flat port of the camera) so it can be expected to significantly outperform



A graph comparing the resolution achieved in the corner of the frame by the WACP and 28-70mm and Nikon 14-24 and Canon 11-24mm behind 230 mm dome ports. The data are measured resolutions from underwater test shots across different apertures. Data source: Nauticam 2017.

the WWL-1. It also benefits from the knowledge that Nauticam learned developing the WWL-1. The downside is that now we are dealing with full frame, so everything must be much bigger! This is one of the reasons that the WACP is designed to work with relatively small lenses, because to work with big pro-lenses it would have to be huge, even more expensive and for all this the image quality gains would be minor (the bottleneck is the port, not the lens).

The graph presents real data measured underwater in Nauticam's optical testing facility. The comparison is the same as with the WWL-1, further above, but note that the values on the axis are different. The Canon 11-24mm does not perform as well as Nikon 14-24mm, in the corners of the frame, primarily because it has such a wide field of view (126° versus 114°). As a general rule, the wider a rectilinear lens the harder it is to get it to perform well behind a dome. It is also important to note that the WACP and 14-24mm were both tested on the same Nikon camera, while the Canon lens, understandably, was tested on a Canon camera. This might also account for the lower resolution recorded by the image analysis software.

The Nikon 14-24mm shows the classic pattern we would expect to see from a dome port, with increasing detailed resolved in the corners of the frame the more the aperture is closed (which brings the virtual image increasingly into focus). The highest detail was obtained at f/16, with a small drop at f/22, probably caused by diffraction. However, in the real world, a resolution above about 800 lw/ph (it stands for line widths resolved in the picture height, but I wouldn't get too caught up in it) in the corner of the frame would look decent, which the 14-24mm achieves at about f/13.

The WACP gives between 2 and 3 stops advantage over the best wide angle lenses and domes in terms of corner sharpness. Damselfish swim into the sun, Egypt, June 2017. Nikon D5 and Nikon 28-70mm @ 35mm. Subal ND5 housing. Nauticam WACP. Seacam 150 strobes. 1/80th @ f/16, ISO 640.

The WACP gives us the ability to fill the frame with a huge range of subjects. Goliath grouper, Cuba, August 2017. Nikon D5 and Nikon 28-70mm @ 35mm. Subal ND5 housing. Nauticam WACP. Seacam 150 strobes. 1/100th @ f/13, ISO 400.

The WACP and the Nikon 28-70mm outperforms the Nikon 14-24mm significantly at all apertures, despite its much greater FOV (130˚ versus 114˚). Furthermore, the WACP resolves greater than 800 lw/ph at all apertures tested. The graph also shows that the WACP produces approximately the same corner sharpness as the 14-24mm when the aperture is at least 2 stops (that is 6 clicks on most cameras) more open. This is equivalent of being able to shoot at f/5.6, rather than f/11 or f/13. Note that these data represent is best case for the 14-24mm, as it was tested here with a large dome, optimum port extension and with the aperture closed down.

I'll save you from another graph, but the same tests in the center of the frame demonstrate that the WACP setup also resolves more detail relative to the pro-quality wide angle zooms. Although the difference is smaller than in the corners (because there isn't the field curvature effect) and the advantage over the 14-24mm is about 1 stop in the center.

In conclusion, the optical tank tests show that the WACP with the 28-70mm significantly outperforms dome ports across the range of apertures and produces useable corner resolution right across the range of apertures from f/5.6 to f/22.

Conclusion

The WACP is a fascinating new product that delivers exceptional underwater image quality, and when used with a zoom lens, it provides a highly flexible optic in terms of FOV and aperture. Both of which take some adaptation to your technique to fully exploit.

It also takes some mental-recalibration to attach a relatively inexpensive zoom lens to your camera as an upgrade to that expensive wide angle pro-lens! Although the price of the WACP (not yet announced) is likely to reassure those of us used to correlating cost with performance!

Any world leading optic, that contains 3 kg of glass for one specific

The WACP combined with the 28-70mm has the widest zoom range I have used underwater and does so with better image quality at each focal length than I have experienced before. Two images of the same scene, one at 28mm (FOV 130˚) and one at 70mm (FOV 57˚). Scorpionfish with fusiliers, Egypt, November 2016. Nikon D5 and Nikon 28-70mm @ 28mm. Nauticam housing. Nauticam WACP (pre-production prototype). Inon Z240 strobes.

I felt that the lens was more prone to flare than a glass dome port, but it was not a significant problem when shooting into the sun. Silky shark, Cuba, August 2017. Nikon D5 and Nikon 28-70mm @ 28mm. Subal ND5 housing. Nauticam WACP. Seacam 150 strobes. 1/100th @ f/11, ISO 400.

purpose, does not come cheap. The WACP also ideally complements the two other water contact optics that some already use for their superior image quality on full frame. The Nikonos RS-13mm at 175˚ (Nikon only) and the 90˚ 15 mm (manual focus only, Sony Mirrorless only). The WACP covers the range 130˚ to 57˚ as tested here, and is theoretically compatible with any camera and housing. When I started photography, I learned that using a zoom means gaining flexibility, but giving away image quality relative to a prime lens. This is another area that the WACP challenges perceived wisdom - now we can have a huge zoom range and better image quality at the same time. We really can have our cake and eat it.

It is still very early days with the WACP. I don't know whether it will be as valuable on a crop sensor SLR with an 18mm to something zoom. I can't yet tell you what is the best 28mm lens to use it with on a FF Canon. And there may be some other excellent lens options for Nikon and Sony cameras, that haven't been tried yet. Time will tell. From the 1960s underwater photographers started evolving from using flat ports to dome ports for their wide angle photos. Perhaps we are now at the start of a new era, where domes will give way to fully corrected water contact optics. Of course, we will still use flat ports and we'll still use domes when they are the best option, but we're lucky to have a new choice.

The WACP is clearly aimed at the most demanding users - primarily full frame stills photographers and high resolution video shooters. The WACP that I used for this article has just been sent on to the guys at the BBC, who have just finished filming Blue Planet II, to test. However, even for those who find the WACP is out of their price range can be encouraged because

The WACP is designed to deliver a wide field of view, with dome beating image quality from center frame to the corners, even at more open apertures. Kittiwake interior, Grand Cayman. Nikon D5 and Nikon 28-70mm @ 28mm. Subal ND5 housing. Nauticam WACP. Seacam 150 strobes. 1/160th @ f/10, ISO 1000.

the technology is certain to percolate through underwater imaging.

Perhaps the most important message to come from the analysis in this article is the reinforcing of an old photographic adage — that it is better to spend money on glass than cameras. We're all keen to upgrade to the latest cameras, often spending $10,000+ for a new camera and housing to get the best image quality. However, what is clear is that megapixels are not the bottleneck for image quality underwater. Those that want the very best quality in wide angle images should be investing in the right glass. Currently that's 3 kg worth!

In short, the WACP won't make you a better photographer, but will make every picture you take better.

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