Aquarius Version 4 Salinity Product Tutorial

00:00 – Introduction

Hi, my name is Shannon Brown and I'm from the NASA Jet Propulsion Laboratory. This video is giving you an overview of the changes for the Aquarius Version 4 salinity product compared to the Version 3 product, which was previously released.

Version 4 is a new product. And we have a lot of improvements that we're going to talk about in this video… give a little bit of an explanation of why we improved them and the results.

If you want more information about the Aquarius mission, go to our website at aquarius.nasa.gov.

If you want access to data or to find out more information about the data, including documentation, go to the PO.DAAC at podaaac.jpl.nasa.gov.

00:55 - Purpose

The purpose of this video is to provide a tutorial to show you the changes to the Version 4 Aquarius product from Version 3. If you want to find out more information about Version 3 and how it evolved, you can go to the website shown here [aquarius.umaine.edu/cgi/data_v3.htm].

So we have several improvements in the Aquarius Version 4 processing. The major improvements will be discussed here although there are some minor improvements, which are found in the documentation available on the PODAAC site.

The major improvements that will be discussed in this video are antenna pattern correction; this is changes to improve the overall calibration of the instrument. We removed some residual biases in the salinity product that were correlated with SST, tracing this back to where they most likely originated in the Aquarius algorithm. And also we generated detailed uncertainty maps. This is the estimated error in each of the salinity products depending on where the measurement is made.

And we also added one new product, which is sea surface density.

01:50 - Antenna Pattern Correction

The Aquarius radiometer measures microwave radiation at 1.4 Gigahertz, which is termed "L-band," through the antenna. The signal is then detected and amplified and used to retrieve sea surface salinity. The Aquarius radiometer antenna receives energy from all directions but mostly from the place where it's looking, the place where the salinity product is geo-located.

But it also has side lobes and these side lobes can fall on the earth, far away from the radiometer over the earth horizon but also can fall off the earth: we see the cosmic microwave background and also the galactic emission from our Milky Way galaxy. These side lobes require a correction. You need to know both the intensity of the radiation coming in, whether it comes from land, or ocean, or even RFI. We also need to know the amount of energy, how it's distributed.

The Aquarius radiometer measures three distinct polarizations: a vertically polarized component, a horizontally polarized component, and a correlation of the two. In an ideal world, it would measure those pure parameters but what the antenna does is it has the effect of mixing them and what we have to do in the antenna correction pattern process is unmix them.

To remove the effects of the antenna pattern on the Aquarius radiometer calibration, we need to know something about the Aquarius antenna pattern. The antenna pattern can be measured on the ground, which is done for smaller radiometer systems, but the size of Aquarius radiometer antenna -- two and a half (2.5) meters -- really made it logistically very difficult, if not impossible, to measure on the ground.

Therefore a smaller version, a scale model version of the spacecraft system, including the Aquarius reflector plus the spacecraft, was measured on the ground. This produced a fairly accurate antenna pattern but to the level that we need a calibration to retrieve sea surface salinity, it wasn't quite good enough. Therefore we supplemented that with a very detailed RF model using very advanced electromagnetic simulation software.

So now we have two patterns: one from the range measurement, which is the measurement that was done on the scale model on the ground; and one from the very detailed model. They didn't quite agree but what we were able to do is to apply them both to the data, compare them to the validation against buoys, against the sea surface salinity model, which comes from HYCOM, and we were able to sort out subtle differences in them and identify which one is more accurate.

So we noticed two residual errors that were likely related to the antenna pattern. We were seeing residual couplings in the comparison between the radiometer calibration and our model for what we expecting to see over the ocean. This was residual coupling between the different polarizations. We were also seeing a bias of the radiometer measurements over the land compared to other radiometers such as SMOS.

What that meant was that we had two problems in the antenna pattern: one is that we were improperly unmixing the polarizations and the other was we were improperly accounting for the radiation that fell off the earth into cold space, which would produce a bias that was small for cold space values and large for warm values… it scales essentially with the brightness temperature of the scene.

When we applied the two different antenna patterns – the range measurement and the computer model – to the Aquarius data, we found that the computer model most accurately unmixed the polarizations compared to what we expected to see. And the scale model produced the best agreement with the other datasets over land. Therefore we produced a hybrid antenna pattern, which had the best part of the measurement that we made on the ground and the best part of the computer model. So essentially the computer model is giving us the cross-pol information. And the scale model, which was a very accurate measurement of the total power originating from the antenna, gave us the measurement of the amount of energy falling off the earth versus the amount of energy falling on the earth.

This conclusion was supported by a special measurement that we made with the spacecraft where we put the spacecraft upside down as we are transferring from a radiometrically very warm Amazon rain forest to a radiometrically very cold ocean. That changed the signal in the backward portion of the antenna pattern and we were able to then see the contribution, because we know the signal from the earth, we were able to see the contribution into the antenna pattern and pick which model was right.

06:20 – SST Bias Adjustment

One of the other major improvements that we made for the Version 4 product was a explicit correction for the SST bias that we observed. Now we had this in the Version 3 product as well but it was an additional evaluation product and it was an empirically based correction. For Version 4, we went back and tried to trace where this SST bias in the salinity might be coming from and identified two places where it's most likely coming from and made more or less physically based corrections to remove this SST-dependent bias on the sea surface salinity.

When we compared the Aquarius salinity measurements to Argo *in situ* measurements and to model measurements from HYCOM, what we found were regionally dependent biases that were very well correlated with the sea surface temperature. For the Version 3 product we made a correction, which is an empirically based correction, to remove this dependence. It looks like the curve on your screen.

Now this was not that satisfying because we really didn't understand where this was coming from.

For Version 4, we did a lot of work in trying to understand in which of the L2 processing algorithms this was coming from. And there are a number of places that this could enter in and we'll discuss those next. To identify where these biases were coming from that were dependent on sea surface temperature, we analyzed the data in various ways by plotting the sea surface biases relative to Argo or relative to the HYCOM model as a function of wind speed, sea surface temperature, latitude, and various other ways.

What we found was that the bias was dependent not only sea surface temperature but also had a dependence on wind speed. This plot here shows a 2-D plot of the bias as a function of sea surface temperature and wind. You can see that the bias not only increases as you get toward higher sea surface temperatures but also changes as a function of wind speed. This really gave us a clue as to where it might be coming from... that it might be tied to the surface roughness correction model or the dielectric model of the ocean surface.

One algorithm where the SST bias could originate is in the dielectric model function. What Aquarius measures is the brightness temperature, and what we're after is the salinity. The dielectric model function is what relates the amount of brightness temperature that we receive versus how much salt is in the water. Salt in the water increases the conductivity of the water, and by doing so increases the reflectivity of the water surface. The more reflective it is, the less it emits and the lower the brightness temperature. But if we don't have that dielectric model function just right, we're not going to be able to relate exactly the salinity to the brightness temperature and we're going to have a bias, which is dependent on the sea surface temperature.

But it's a little bit more complicated than just the dielectric model function. You also have to worry about wind and waves on the ocean surface, that tend to roughen up the surface... much like if you took a highly polished mirror and rubbed sandpaper over it, you wouldn't be able to see your reflection as clearly. The same thing happens as you have wind and waves that roughen up the ocean surface. You're decreasing the ocean reflectivity, which, in turn, increases the emissivity or the amount of brightness that we see for a given salinity. So for the same salinity, if you have a smooth surface, you're going to see a lower brightness temperature. As you roughen up that surface, you're going to see a higher brightness temperature. And if we don't accurately account for that, we're going to bias our salinity measurement.

What we do is we use a scatterometer, which is a radar onboard the Aquarius mission, to tell us how much roughness there is on the ocean surface to make this correction. And this enabled us to go into the model functions for the roughness correction -- which is the one that removes the signal from the waves -- and also the sea surface temperature correction, the dielectric model, which is what relates the salinity to the brightness for a smooth surface. And by making very small adjustments within the uncertainty of this model, we were able to remove the biases that we were seeing and that's included in the Version 4 product.

Another algorithmic correction that we had to do, which is also highly dependent on the sea surface temperature, is a correction for the atmospheric absorption. So we have the signal that originates from the ocean surface, which has to propagate through the atmosphere to get to the radiometer. Now the atmosphere absorbs some of that energy, and then re-emits it based on physical temperature. Most of that absorption at L-band, 1.4 Gigahertz, comes from oxygen, which makes up about 20% of the atmosphere. If you don't have the absorption perfectly tuned, the amount of energy that the oxygen absorbs as the signal propagates, then we're going to have an error that is dependent essentially on the temperature of the air.

And because the temperature of the air is very highly correlated with the temperature of the sea surface, we'll get – on a global average – a bias from that algorithm, which is correlated with the sea surface temperature. So what we were able to was to make small adjustments to the amount of L-band energy that oxygen absorbs in the atmospheric absorption model, which we found was very well correlated with the biases that we were seeing in the salinity product compared to SST.

We were able to make a small adjustment, within the uncertainty of that model to reproduce the errors that we were seeing and, hence, remove those from the Version 4 product. So the approach that we used for Version 4 is much better than the empirical correction that we had on Version 3. For one, Aquarius measures the salinity with three independent radiometer beams that form the swath. For Version 3, we had to make a separate empirical correction for each one of those. Now the benefit of this approach -- going back in to the dielectric model function, the roughness model function, and the atmospheric absorption model function – and making the corrections there within the uncertainties of this model, as opposed to just making an empirical correction to the salinity products themselves, was that this correction is now more physically based.

We made adjustments to the physical models, which relate the brightness temperature measurement to the salinity measurement, which are valid for all the horns. So instead of adjusting each horn individually, we're able to just make one adjustment in each of the models, which removes the bias in all the horns without having to adjust each one individually. This is much more physically sound and why we included it in Version 4.

12:35 - Addition of Uncertainty Estimates

The final thing that we want to cover in this tutorial video for Version 4 is the explanation of the uncertainty maps, which are new for the Version 4 product and provide the users with an estimate of the uncertainty regionally -- for whatever region they're working on -- or even globally. The full documentation is available online at the PO.DAAC and it can be found here.

As a user of the data, it is very important to understand the uncertainty in it. We, as radiometer experts, are very well versed in where the radiometer retrieves salinity very well and where it might have a little bit more difficulty in doing so. In those areas where it has more difficulty, it'll have higher uncertainty. With the uncertainty product, which is now available for the Version 4 data, we've tried to convey -- in a very easy and graphical manner -- where the product has higher uncertainty and where it has lower uncertainty.

We can group uncertainties into random uncertainties, those that average down as you average more data and systematic uncertainties, those that don't average down that could be either regionally or temporally dependent. So what we did was we broke down the uncertainties into the random component and into the systematic component. And the summation of the two is what you find in the final uncertainty product that is available.

So examining these uncertainty maps gives us a good overview of where the salinity retrieval can be done very well and where it has more limitations. The biggest one that you'll see is a dependence with latitude. This arises because the salinity signal -- that is how much change in salinity causes a change in brightness temperature – changes with sea surface temperature. So in very warm water, in the tropics, we're very sensitive to sea surface salinity. That is, for a small change in salinity, it produces a much larger change in brightness temperature. Therefore we can detect that with much lower uncertainty. As the water gets cold, our sensitivity to salinity reduces dramatically, so that the signal-to-noise decreases quite a bit and we have much more uncertainty, particularly in the random component.

So that's the most dominant feature we see in the map. You also see biases increasing near land. Land is very radiometrically warm compared to the ocean. So as we get near land, we're starting to pick up some emission from the land surface that biases the radiometer measurement. We do make a correction for it but to make that correction accurate, we need to very accurately know the brightness temperature of the land, over a very wide area. Because there is some uncertainty in that, there is some uncertainty with the salinity retrieval as we get close to land and that error increases the closer and closer you get to land.

The last major feature that you're able to see in these uncertainty maps is the contribution due to RFI. RFI is Radio Frequency Interference. It's essentially manmade radio emissions, interfering with our measurement because the Aquarius radiometer is sensitive to the natural emission from the earth but it's also going to receive everything that's coming up from the earth that is produced by cell phones, walkie talkies, various things that use RF transmission. We see a lot of this RFI near Europe and also in Asia. And we do make provisions to remove it but it's very difficult because RFI is random, we're not quite sure how much is ever going to be present at any given time.

Therefore, as we get close to Europe and close to Asia over the ocean, we're getting a lot of this RFI coming in through the antenna side lobes, if you recall the discussion we had earlier in this video.

And in cases where it's significantly biasing the measurement, we flag it and don't include it in the Level-3 product. And we can do that filtering but some always leaks through. So what we've done is we've tried to estimate how much is leaking through and include an uncertainty for that in the product. But, regardless, we're going to have higher uncertainty near areas where we see a lot of man-made Radio Frequency Interference over land.

On the Level-2 product you have less averaging, so your random uncertainty is a bit higher. As you average the data to the Level-3 gridded product, you're averaging a lot of data. The random component reduces but the systematic component doesn't. So you're mostly dominated in the Level-3 product by systematic error. And in the Level-2 product, you have equal contributions from the systematic and the random error. The reason why we did this is because you have to properly account for this as you're averaging the data. Using the Level-2 product, you can take the random uncertainty into however you're averaging the data, then you can compute the total uncertainty in the end, plus the addition of the systematic component.

Now for the random component, the major contributors are the radiometer noise, shown here as the "NEDT," and also the wind speed, which has a random component, essentially our ability to estimate the roughness correction, which also has a systematic component. Now when we go to the Level-3 product, the random component from the radiometer averages down quite a bit.

But the major contributor is the correction for the wind speed. If you remember back to the previous section in this tutorial -- how we have to correct for that rough ocean surface -- that is actually one of the biggest signals that we measure, next to the salinity signal. So if we don't have that wind speed correction just right, it produces an error and that residual error is the largest that remains in the systematic error budget.

So a new product that we've added to the Version 4 product is a sea surface density product.

Now sea surface density is just derived from the salinity that we measure and also SST. We use an ancillary SST, which is the Reynolds Optimally Interpolated SST. The density product can be found on the Aquarius website, for the daily and weekly products, and is also included on the Level-2 and Level-3 product of Version 4. So what you're seeing here is an example of the density product over time from the Version 4 Aquarius data. And it shows what you might expect to see. In areas where you have colder, saltier water you are seeing higher densities. And in the tropics -- where you have warmer, less salty water -- you're seeing lower densities. Density is really important and drives ocean circulation and the reason why we included on the Version 4 product.

18:50 – Wrap Up

So to wrap up this tutorial on Version 4, I want to finish with what you can expect to see in the next version of the Aquarius data product, which is going to be Version 5. Measuring sea surface salinity from a radiometer is a very challenging measurement, which, in a sense, means we're never done calibrating.

So for Version 5, we have a number of calibration improvements planned and these result from our continued understanding of the performance of the radiometer and fine-tuning that we can do to some of the radiometer calibration parameters. And this is enabled by having almost four years of Aquarius data.

Another area where we're making improvements is in addressing some of the residual, regionally dependent and temporally dependent biases that we have identified in the data comparing to *in situ*. We've identified some of the algorithms that can potentially be causing these and plan to investigate and make improvements to those algorithms for Version 5.

Another area is improving the RFI correction. As we get more data from L-band radiometers such as SMOS and SMAP, we can better estimate how much man-made emission is coming up at us and, with that, we can make a better correction for areas near Europe and areas near Asia.

And then finally, we have some additional products. One is a rain accumulation product, which is essentially what the near-surface salinity gradient is going to be when you have a rain event. Rain freshens the water and what we measure is essentially the salinity right at the surface.

So this will give users an estimate of what the near-surface salinity is based on, how much and how long ago it rained for any particular Aquarius measurement.

Well that brings to a close this tutorial, the first for Aquarius. We hope that you learned something from it and look for more of these over time.

Thank you and enjoy the data!