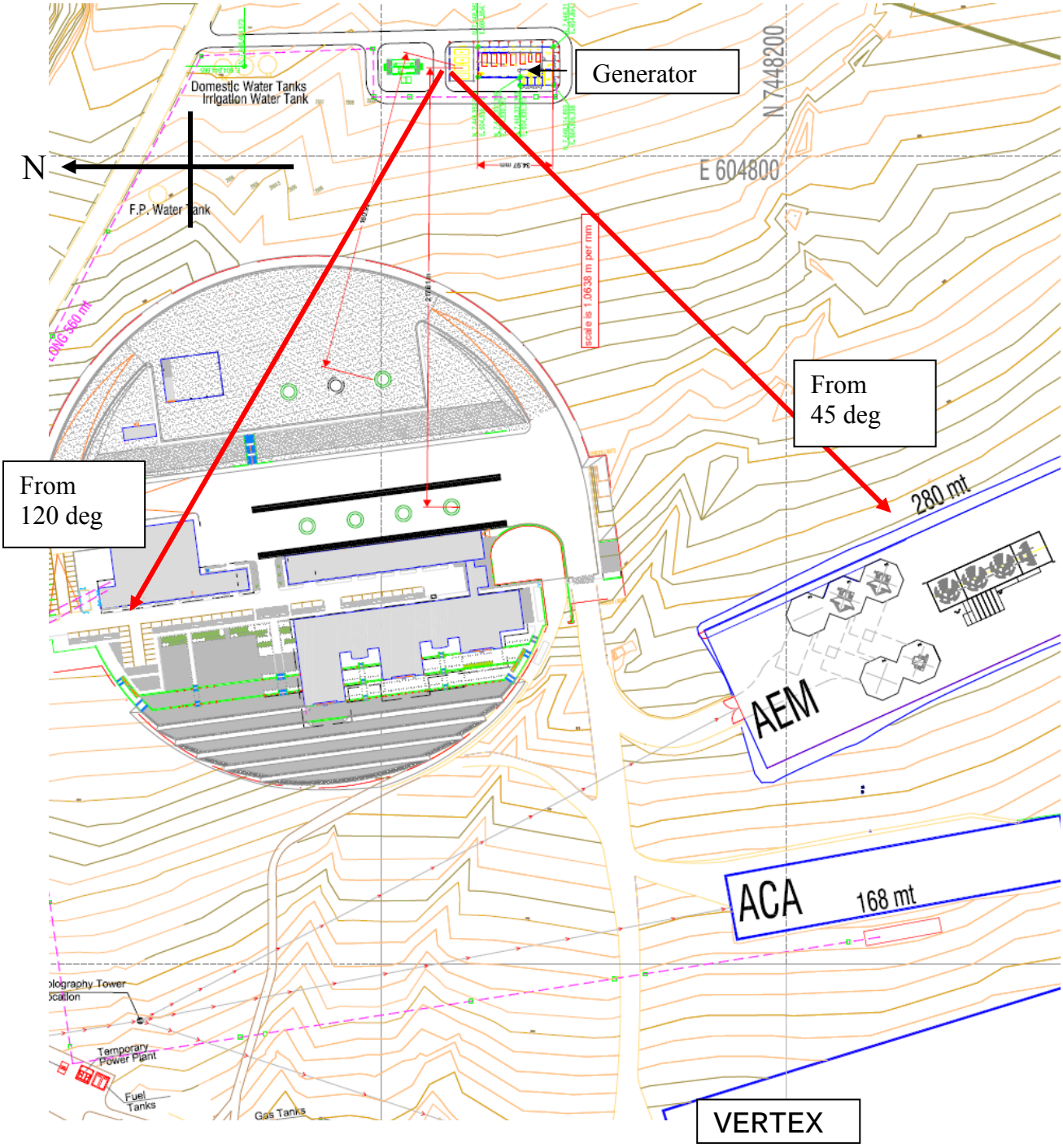
Location of the Power Generators

Earlier this year a decision was made to go ahead with the “Island Mode” approach to generating electrical power for ALMA. A location at the upper (Eastern) end of the site was chosen. Next to the generators will be the 23 kV switch-station from where the power line will run up to the AOS. In choosing this location we unfortunately overlooked the fact that the surplus heat produced by the generators will be carried over the areas where we are planning to do the optical pointing tests on the antennas, and that the turbulent mixing of the warm and cold air will inevitably have a negative effect on the “seeing”. Nick Whyborn pointed out this problem and provided this diagram.

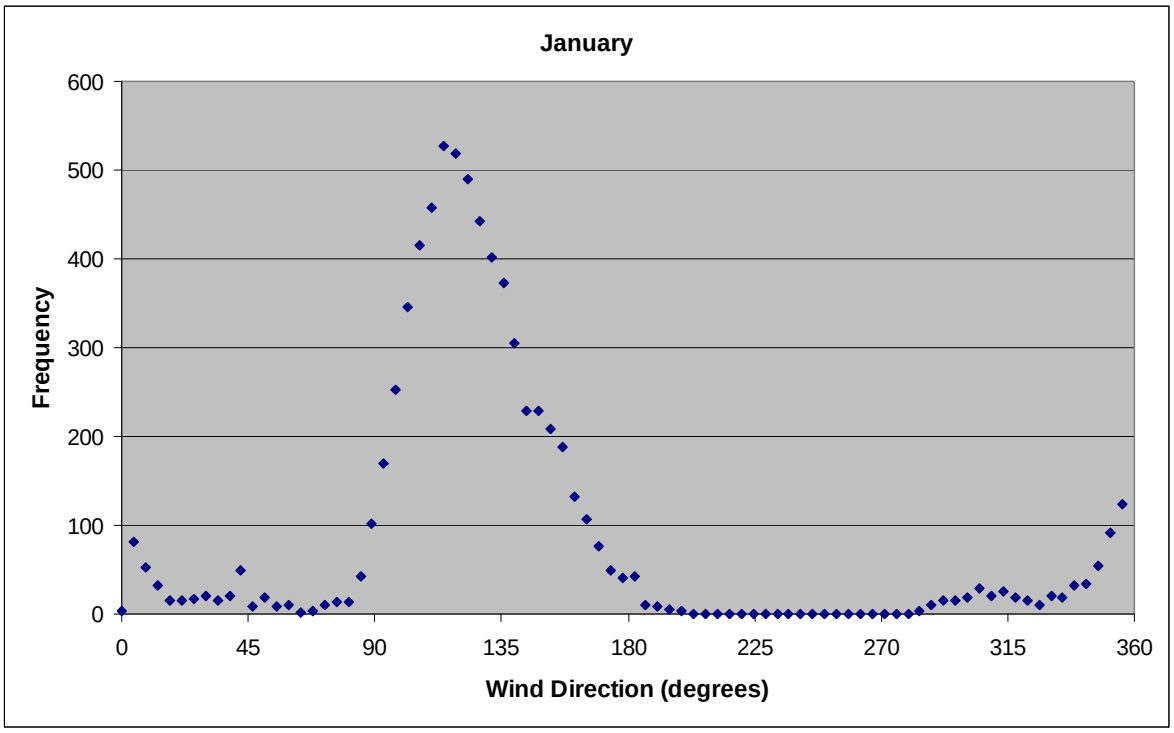


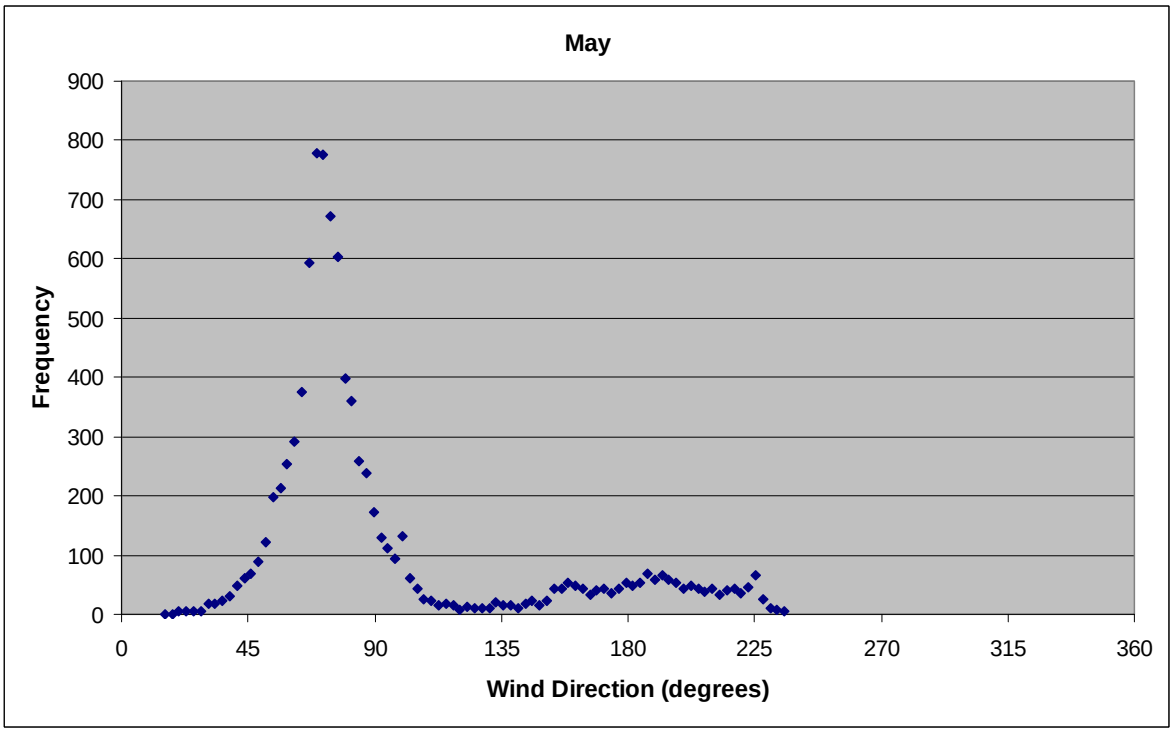
(I added the arrows and labels.)

The generators are almost due East of the AIV test area. It is clear that winds from the East – in particular roughly in the range from 45 to 120 degrees azimuth as shown above – will carry any

hot air produced by the generators across this area and/or the areas where the manufacturers are required in their contracts to do their testing. It turns out that the wind is in this sector for a large fraction of the clear night-times, which is when the optical pointing work has to be done.

People who work at the OSF would be forgiven for thinking that the prevailing wind is from the West, as it very definitely is at the AOS. It is true that the wind at the OSF is from the West in the daytime (particularly in the afternoons) but at night the radiative cooling of the mountainside causes the cold surface layer to flow downhill, which means it comes from the East. This is the so-called katabatic wind. Here are some plots of the wind direction from the "AIV" weather station near the middle of the site showing the narrowness of the distribution[1].





[1] These are just examples from single nights – we could do more complete studies, but having looked at a dozen or more I am confident that the basic pattern would be that same. Note that the flow is less strong when it is cloudy but that does not help because we can't do the optical pointing tests then.

We can try first to predict how bad this effect will be from first principles.

When ALMA is fully operational the power being generated is expected to be about 7MW. With 35% efficiency, this means that about 13 MW of waste heat is being produced. We can in principle recover some of this to drive a second stage turbine and perhaps provide heating, but clearly there will still be many MW left over and, as far as I can see, there isn't really anything else we can do with it except put it into the atmosphere. It will then rise and mix with the cooler surrounding air. In the early stages of operation, which is when most of the testing at the OSF is expected to occur, the amount of waste heat will be smaller, but I can't see it being less than 2MW at, say, the middle of 2011.

To get a rough idea of the numbers involved, note that the thermal capacity of dry air at the altitude of the OSF is about 1kJ per m^3. This means that for each MW of heat we have to warm a volume of air V every second, such that the product of $\Delta T*V$ is 1000 K m^3, where ΔT is the temperature rise. Thus for 2MW we need to warm for example 10 m^3 s^{-1} by 200K.

This hot air will obviously rise and mix but, without knowing more about fluid-flow theory and the like, I can't guess what the distances and heights involved would be[2]. What is clear is that the product $\Delta T*V$ stays constant so, by the time the temperature contrast is down to 1K, the volume involved is 2000 m^3 s^{-1}. If the wind speed were 5 m s^{-1} the cross-section of the plum would then be 400 m^2. Again one cannot work out the exact effect on the seeing without a detailed model, but a relevant number is that the thermal coefficient of the path through dry air is close to 1 part per million per Kelvin. Thus a 1K temperature difference over a 1 m path is easily sufficient to destroy coherence at optical wavelengths.

As a practical test of what the effects might be, Rainer Mauersberger set up an optical telescope down-wind of the existing 650 kW diesel generator. He reports that there is indeed a strong effect in the part of the sky above the generator with the seeing being very poor – many arc seconds in the worst effected area. The causal connection was checked by moving to a different position. Note that the effects observed were almost certainly produced by the hot air from the generator's cooling system, since the actual exhaust is hot and narrow and produces "seeing" that can be observed with the naked eye (in daytime) – i.e. at the level of an arc minute or more.

It seems to me that the conclusion that the optical pointing measurements will be at least somewhat impacted by the generator is inescapable. I cannot, however, see how to make a meaningful quantitative estimate of how bad the effect will be without putting in a large amount of time and effort. This means that we have to either (i) make a decision to move the generator based on the above general arguments and the qualitative results of the tests, or (ii) continue with the present location and make plans for the possibility that we will not be able to perform the optical testing as planned at the OSF.

Regarding option (i): the foundations for the new generator are already in place. Here is a recent picture.

[2] It may well be that the best condition is one where the waste heat is ejected in a single rather hot and narrow exhaust plum which would rise quickly and stay well confined until it has passed over the site.

If we are were going to move to a new location this would have to be redone. In addition the 23kV line connected to the AOS would have to be extended to the new location. Massimilliano has explored the possibility of moving just the generator, but this turns out to be impractical – the generator and the 23kV switch-gear need to be close together. This is likely to be the larger difficulty because the contract for the 23kV system, which is due to go to ESO Finance Committee at its next meeting, would have to be revised. It is clear therefore that moving to a new site will involve substantial cost and delay and the delay itself may add further to costs if we have to buy further generators to keep us going in the interim.

Regarding option (ii) there are three possible outcomes: A) it turns out that the effects are not significant, B) only the testing at the AIV location is significantly impacted, and C) it proves impossible for the manufacturers to demonstrate that they are meeting the pointing requirements.

In case A) of course we give a big sigh of relief and move on. In case B) we would presumably have to do our verification of the pointing performance at the high site. (I suppose the possibility of yet another pad at the OSF but above the generator could be considered.) Doing this at the high site would perhaps not be a huge problem since, by the time the new generator is in operation (expected to be by the end of 2010), these tests should be fairly routine. In fact one can see some advantage in doing the tests under the realistic conditions. Operations like installing and aligning the OPT will however be much harder than at the OSF.

Case C) seems to me to be considerably more difficult. I suppose we would have to accept the antennas with waivers and then do the tests at the high site. If the antennas then did not meet the spec we would either have to get the manufacturers to work on them at the AOS or the antennas would have to be brought down again, in which case checking that the remedial work had been successful would be a problem.

As things stand therefore we have to make a difficult choice between the safe option of moving the generator, which will be expensive and will delay the transition to permanent power (and communications to the AOS since that goes in with the power line) and staying with the present plan and facing some risks of complications with the antenna testing further down the line.

The first question therefore is whether anyone can see a third option that might be more advantageous. If not, then thoughtful opinions on which course to take would be welcome.

Richard Hills 19th Aug 2009