Deliverable D2.2: Structure and upgrade strategy of the Cloudnet processing chain

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Cloudnet Scheme - overview

Objective

The original objective for Cloudnet was the routine automated evaluation of the representation of clouds in numerical models using observations derived from a combination of ground-based remote-sensing instruments. Evaluating the representation of clouds in climate and numerical weather prediction (NWP) models is not straightforward. For NWP models, this task is compounded by the expectation of a good forecast, as well as the reliable representation of the specific cloud parameters themselves. Cloudnet has developed and implemented a comprehensive suite set of objective metrics for the evaluation of model cloud parameters, in continual joint collaboration with operational modellers. The set of evaluation metrics is designed to investigate both the climatological aspects required of a climate model, and the ability to forecast the correct cloud at the right time, a necessary validation for NWP.

Cloudnet scheme

The Cloudnet concept is outlined in Fig. 1. **Level 1** deals with the processing of observations from different instruments and their subsequent combination to provide a single synergistic product **(Level 1c**) on a well-defined time-height grid. All individual observations are pre-processed, quality-checked, and Cloudnet-formatted at stage **Level 1b** (**Level 1a** describes optional raw instrument data that may or may not have been quality-checked and correctly formatted – most of this pre-processing is now performed internal to the instrument or on-site). **Level 1b** includes model output that is also in Cloudnet format.

Level 1c is the basis from which all Cloudnet products are created. High resolution products, at the native instrument resolution if possible, are created in **Level 2a**, and are used for all scientific studies. Specific products for model evaluation are created in **Level 2b**, where the high resolution products are averaged onto the grid of each individual model, and in **Level 3** and beyond, amassed into monthly and yearly files containing a wide range of statistical measures. These include: means, distributions, and joint-pdfs for creating the contingency tables used for deriving the skill score of choice. From these files, a wide range of metrics are then be routinely plotted and analysed.

Additional Community retrievals

The design of the processing framework also makes it simple to add new retrieval methods that can be applied across all sites and instruments. The new algorithm should respect the in-built quality control flags, and propagate the instrument uncertainties through to the retrieved parameters. The standard procedure is to start from the target categorization dataset (**Level 1c**) where possible, as this contains the relevant information required for providing consistent uncertainty estimates.

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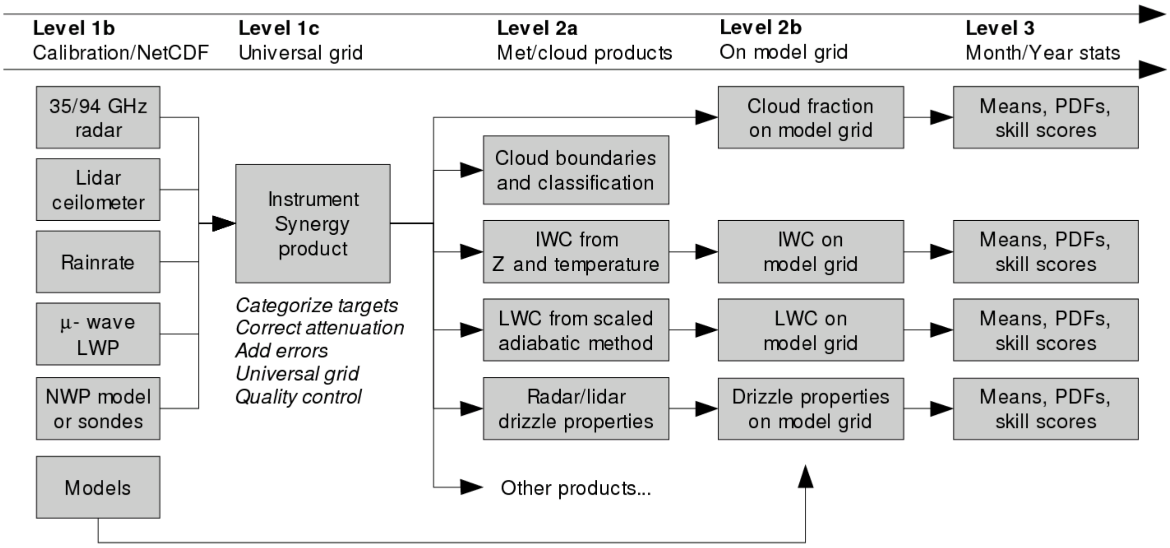

Figure 1: Overview of Cloudnet processing chain

Upgrade strategy

This deliverable relates to the following tasks:

- Task 2.2: Optimization of cloud profiling
  - Task 2.2.1: Improvement of observing strategies, implementation of new data products and optimization of the processing chain.
- Task 2.3: Integration of aerosol and cloud observation capabilities
  - Task 2.3.1: Instrument synergy

The exploitation of synergies and the development of common observing strategies and standards are the main objectives of these tasks. The synergy of EARLINET and Cloudnet facilitates the increasing scientific interest in combined aerosol and cloud observations to study aerosol-cloud interactions. A major goal is the innovative and sustainable advancement of cloud-related observations within Cloudnet and ACTRIS as a whole. Cloudnet stations have the capability of operating a continuously (24/7) measuring network with NRT data provision but the challenge is the immense amount of data delivered in particular by the cloud radars, which so far leads to restrictions in the full storage and exploitation of radar information.

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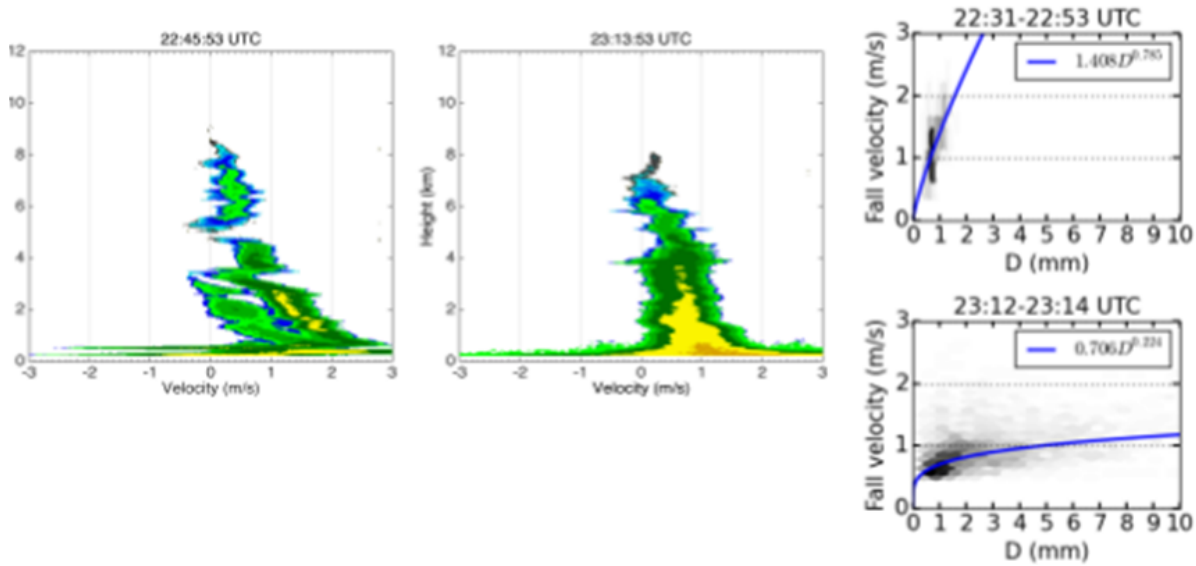

Figure 2: Doppler spectra showing multiple ice populations in the same volume. The ice populations have different densities, which retrievals should take into account.

Exploit cloud radar Doppler spectra

Cloud radar Doppler spectra contain the full hydrometeor vertical motion distribution. Hence, it is possible to diagnose the presence of two or more distinct hydrometeor classes within a single volume, separate each component, and perform microphysical retrievals on the two components independently (see Fig. 2). Discrimination between liquid and ice in mixed-phase cloud, precipitation and liquid cloud, and between multiple ice populations arising from competing growth mechanisms, are all achievable.

The future goal is the exploitation of the full Doppler spectra available from cloud radars, however storing raw Doppler spectra from continuous measurements over longer periods runs into practical issues because of the huge data volume, increasing the data volume by a factor of 256 to 512 (depending on the chosen number of bins in the FFT processing). Therefore, specific storing and evaluation strategies will be developed with the aim to evaluate Doppler spectra during the observation and store only compressed information on multiple peaks and skewness of the spectra, from which higher-level data can be obtained off-line. Methods have been proposed that perform quasi-lossless compression of the Doppler spectra through identification of signal-free regions; implementation of these will proceed once robustness has been demonstrated.

The interim solution is to use multi-peak determination which is already produced routinely by most operational cloud radar systems. The updated classification scheme will obtain bulk moments of the distribution for each identified peak, i.e. reflectivity, mean velocity and spectral width (Z, v, σ) for each peak. This allows the scheme to diagnose multiple hydrometeor distributions in a single volume, and potentially separate liquid, insects, drizzle, rain, and multiple ice distributions. Appropriate retrievals can then be performed separately for each peak identified, therefore allowing, for example, both a liquid and an ice retrieval, within the same volume.

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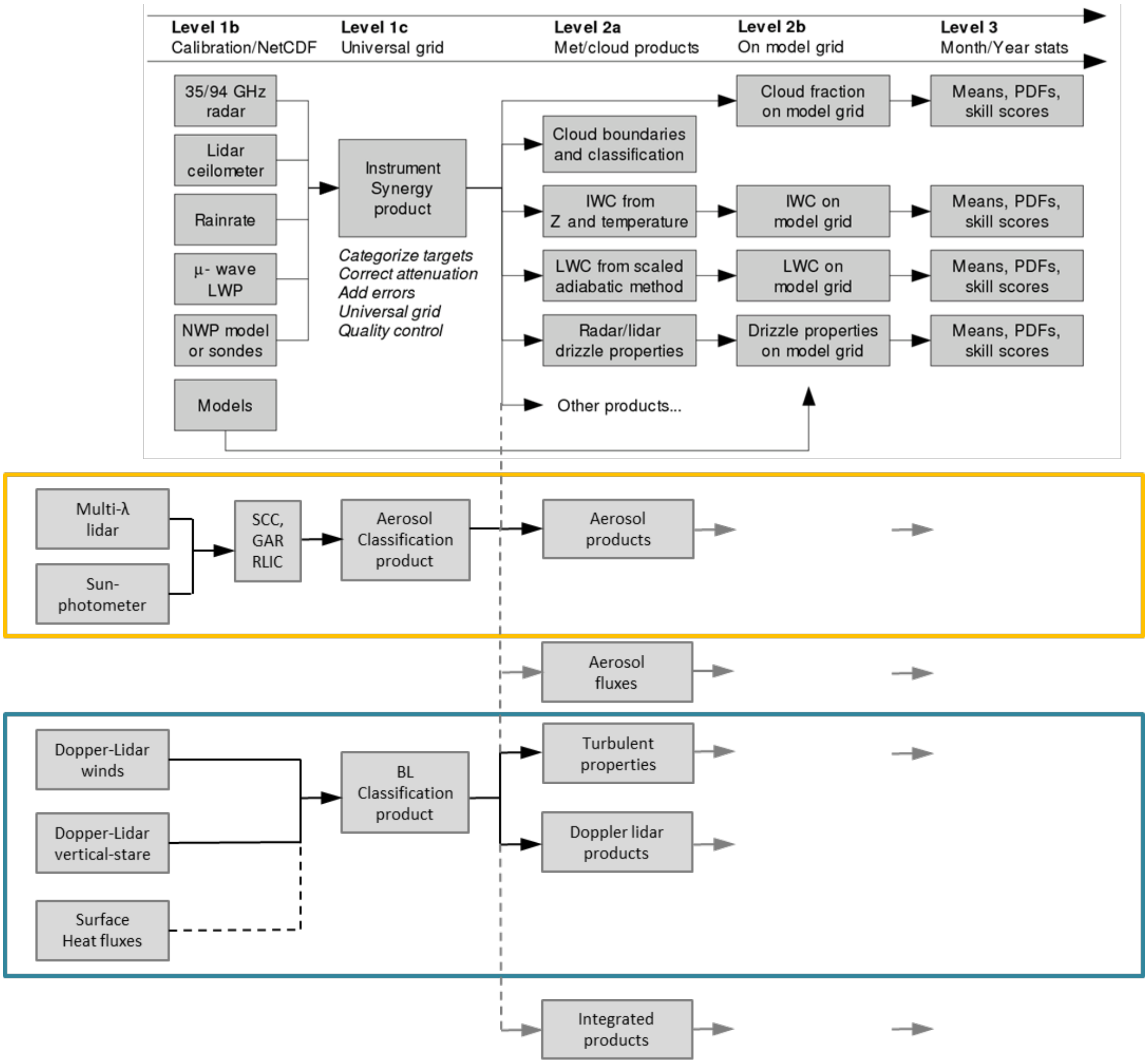

Figure 3: Planned updates to Cloudnet processing scheme. Synergy with planned EARLINET (in orange) and Doppler lidar (in teal) classification schemes will lead to new integrated products, including aerosol fluxes.

Extend aerosol classification with EARLINET synergy

The current classification product contains a single all-encompassing aerosol type, essentially the qualitative recognition of the presence of aerosol. Quantitative retrievals, classification of aerosols, e.g., in terms of pollution or dust, and investigation of aerosol-cloud interactions are only possible with more sophisticated lidars based on multi-wavelength and polarization techniques as applied in EARLINET. Therefore, the current classification will be extended to multiple aerosol types through the use of multi-wavelength Raman lidar systems, which are now operating at many Cloudnet stations. High temporal resolution versions of EARLINET retrievals (SCC) can be applied to automated systems that can be operated continuously. Details are available in the ACTRIS-1 deliverable D5.8: Modified software for aerosol retrievals and in ACTRIS-2 deliverable D2.1: Structure of the level-based EARLINET data processing chain.

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Additional classes and reduced uncertainties will be obtained by the addition of sunphotometer data, through use of the GARRLIC algorithm. Synergy with cloud retrievals provides seamless cloud and aerosol-typed profiles, with the potential for diagnosing aerosol and precipitation in the same volume. The aerosol processing scheme (Fig. 3) will follow the same conventions as the standard Cloudnet processing scheme, with creation of a single aerosol classification product as the basis for all higher-level products.

Boundary layer classification from Doppler lidar

Many Cloudnet and EARLINET sites have started to implement Doppler lidars, which have recently become commercially available for reasonable prices. It is expected that all Cloudnet sites will deploy Doppler lidars in the near future. Doppler lidars allow the observation of horizontal and vertical wind in the PBL and at cloud base, from which turbulent and other properties can also be derived.

The processing scheme will use the profile of horizontal wind and turbulent properties, together with the potential addition of surface heat fluxes from sonic anemometers, to create a boundary-layer classification. This boundary-layer classification will identify the source of mixing source of mixing such as surface-driven, cloud-top driven, shear, mechanical (friction), and include internal layers and blending heights where possible, to give a full picture of the mixing processes occurring in the lowest 1-2 km of the atmosphere.

The Doppler lidar processing scheme (Fig. 3) will follow the same conventions as the standard Cloudnet processing scheme, with creation of a single boundary-layer classification product as the basis for all higher-level products.

New instrumentation

The addition of multi-wavelength Raman lidar systems and Doppler lidars provides additional possibilities. Water-vapour profiles are of particular interest to investigate hygroscopic particle growth and cloud formation. Many EARLINET lidars are equipped with water-vapour Raman channels, although the measurements are not yet standardized. Raman-lidar observations are limited during the daytime and in the presence of clouds; to overcome this, the combination of Raman lidar and microwave radiometer to synergistically derive water-vapour profiles at combined stations is planned. Turbulent properties from Doppler lidars complement Doppler radar observations in-cloud, but are also capable of obtaining aerosol vertical fluxes when combined with aerosol lidar (this possibility is being explored in JRA2).

Data from sonic anemometers (surface and mast/tower), sodar and radar windprofilers are also available at many Cloudnet sites, and provide additional complementary information useful for constraining many retrievals. Procedures for ingesting these within the Cloudnet framework will be written.

All developments will include standardization of the products, definition of metadata, definition and implementation of error products, and documentation.

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Network infrastructure

The Cloudnet infrastructure is displayed in Fig. 4. The internal Cloudnet server (in blue) consists of five entities: FTP server for incoming data; core processing server; database; archive; and webserver. There is continual automated data inflow from Cloudnet stations and from NWP modelling centres. Cloudnet stations have two options: 1) transfer raw data to the core processing server (via FTP server) for all processing on site (in coral); or 2) perform the Cloudnet processing scheme on-site (in purple), and then transfer. The second option is the preferred method as it provides immediate access to Cloudnet products on-site without waiting for transfer of data to the core server, processing and transfer back to the site; this also provides additional redundancy and robustness. Data from NWP modelling centres (in green) is pre-processed on the core processing server, and transferred as required to the Cloudnet stations hosting the Cloudnet processing scheme on-site. Note that this allows processing through all levels directly on-site. The webserver and database provide external links to the public, either directly or via the ACTRIS database at NILU.

An important feature of the network is the potential 2-way flow of information between a Cloudnet site and the central Cloudnet server. This provides a channel for software and calibration updates, and there is also scope for direct update of model performance to NWP centres if requested.

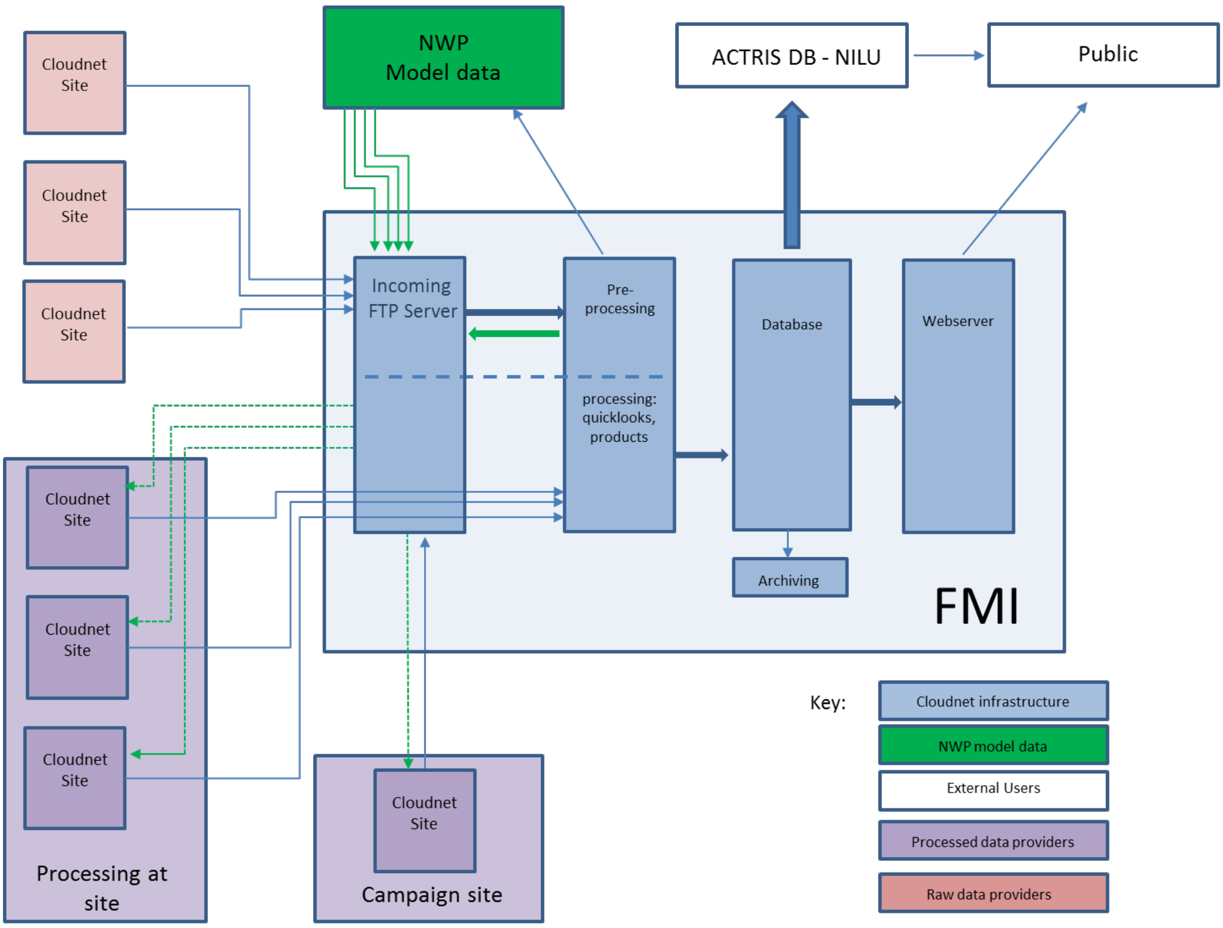

Figure 4: Overview of current physical network

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Updates to network infrastructure

The planned update to the Cloudnet infrastructure is displayed in Fig. 5, with major additions being two new instrument and processing chains: EARLINET (in orange) and Doppler lidar (in teal).

It is envisaged that the core processing servers will remain separate entities while testing and implementation is being performed. This ensures that modification of one system does not impact the standard processing scheme while updates and tests are being performed. This separation will also allow individual instruments that are not necessarily included in a Cloudnet station (while on a campaign for example) to be processed in a similar manner where possible. As for the standard Cloudnet scheme, it is planned that there will be the option to perform all processing on-site, or on a core central processing server.

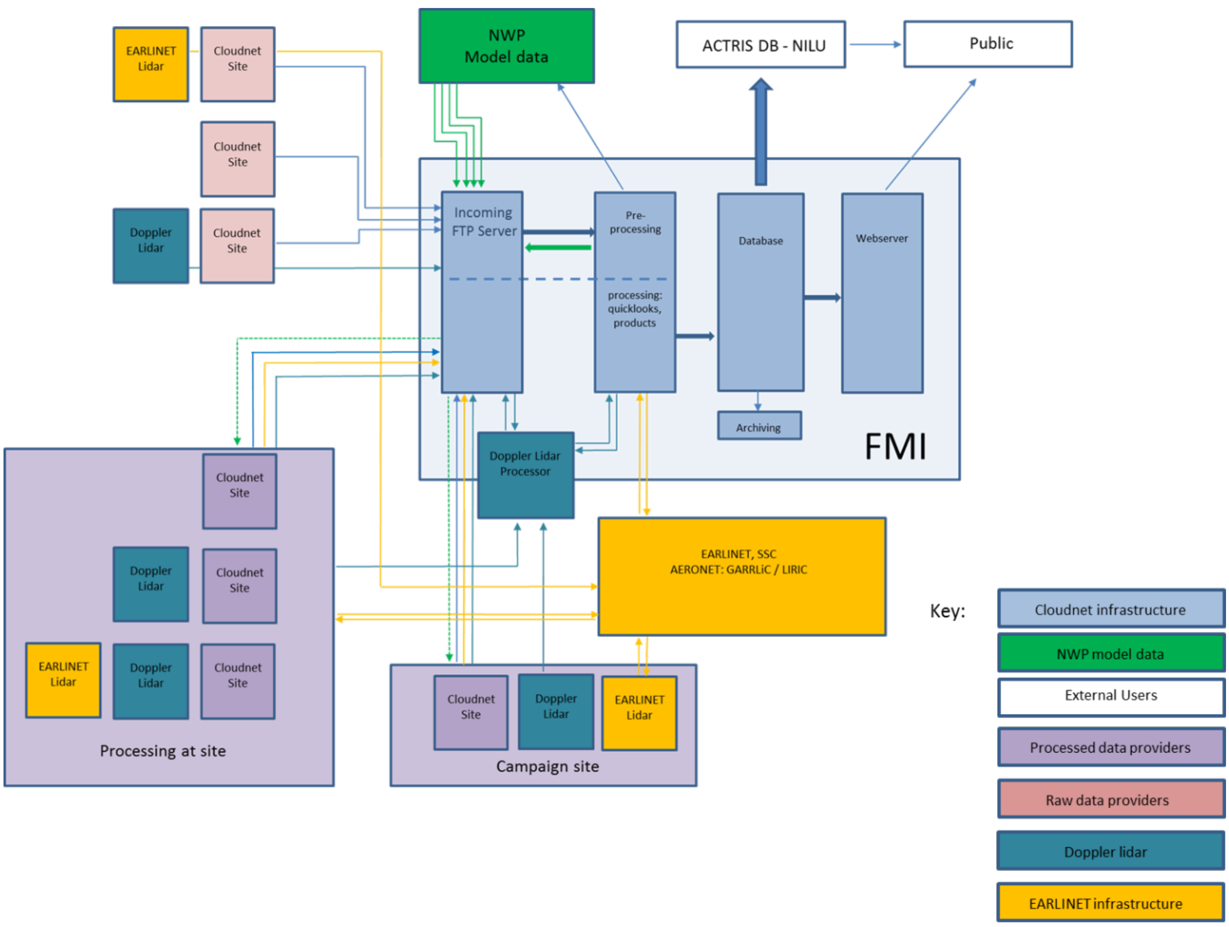

Figure 5: Planned upgrade to physical network

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