CLOUDNET USER REQUIREMENT DOCUMENT.

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This document outlines the requirements of the users of the processed and unprocessed data arising from the CloudNet project. Discussion will include which variables model users wish to evaluate, whether models and observations should be compared in model space, observation space or a third space, consideration of comparisons between different models and whether any problems occur with inconsistent or biased processing of model and observational data.

1. INTRODUCTION TO LARGE-SCALE MODELS.

Large-scale models are principally used for either numerical weather prediction (NWP) or climate prediction. The difference in the atmospheric parts of the models is mainly a matter of the scale, although data assimilation performs an essential part of NWP and there are feedbacks such as aerosols which are modelled within the climate model but not NWP. Within operational NWP, models are run at a variety of scales, typically 10 km to 100 km horizontal resolution and 10 m to 1000 m vertical resolution (higher resolution in the boundary layer). Development of these models with time is likely to see the horizontal scales drop to around 4 km, or lower. Timesteps typically range from 5 minutes for mesoscale resolution to 20 minutes for global resolution. Climate models have coarser resolution than these.

Models typically store only a few ‘prognostic’ fields at each gridpoint, usually in the form of gridbox means, for which equations describe the time evolution. Other information must be parametrized diagnostically. Often the subgrid-scale distribution of the quantity is important in describing the evolution of the model - this distribution also needs to be parametrized.

An important part of large-scale models relates to the representation of clouds. Clouds play a role in the radiative transfer of heat in the atmosphere, and in the water cycle, and strongly influence the atmosphere on a wide range of time and space scales. It is important that the performance of large-scale models in reproducing cloud properties is evaluated. This applies to the prognostic and parametrized fields, and to grid-scale and subgrid-scale information.

2. VARIABLES OF INTEREST TO A LARGE-SCALE MODEL.

All current large-scale models operate using a number of ‘large-scale’ prognostic variables. These usually represent the mean conditions within a large gridbox of a basic meteorological quantity, for example, the amount of water vapour within a gridbox. From these large-scale variables the effect of physical processes, such as radiation, is estimated, assuming extra information which is not

available from the prognostic variables, such as particle size distributions. This extra information and the equations which are used to describe the evolution of the prognostic variables need to be ‘parametrized’. Errors in the model prediction of a particular aspect of a cloud system can occur through errors in the prognostic variables or errors in the parametrizations that use the prognostic variables. Both need to be assessed. Some large-scale models will contain inconsistent assumptions in different physics schemes, which is undesirable.
Note that different large-scale models do not always contain the same large-scale variables, and usually do not contain the same parametrizations. Therefore, the direct comparison of the predictions of one model against another is sometimes difficult.

In general, there are several variables which are of importance to large-scale models and relate to quantities the CloudNet observation sites may be able to provide information about. The relative importance *depends upon the model*. These are listed below:
i) Liquid water content and supercooled liquid water content
ii) Ice water content
iii) Vapour content
iv) Cloud fraction
v) The characteristics of the moisture distribution in a gridbox, such as the probability density function, variance and skewness, over a range of spatial scales.
vi) Fraction of the gridbox containing a mixed phase region
vii) Rainfall rate, snowfall rate
viii) Vertical correlations of these quantities
ix) Particle sizes, distribution of particle sizes
x) Shape of ice particles, ice particle densities, ice particle fall speeds
xi) Optical depths

It would be of considerable use if CloudNet is able to provide information about any of these parameters, on a climatological or case study basis.

a) More details on variables of interest.

The following is a list of the most useful parameters, although other observationally derived parameters may also prove to be of value.

i) Ice water content: The mixing ratio of all frozen condensate which is present in the model. This is particularly important for cirrus clouds, which are of optical thickness of order 1, where the radiation is particularly sensitive to the ice water content. This is also important for other clouds, such as altocumulus, where the amount of ice will influence whether a supercooled liquid layer can remain present. The correct prediction of ice water content within a frontal system also allows confidence in the microphysical parametrizations such as the ice fall speeds and size distribution parameters, or the conversion of ice to snow (this depends on the formulation of the model).

ii) Liquid water content: The mixing ratio of all non-precipitating liquid condensate in the model. This is important for similar reasons as ice water content and in two additional ways. Firstly, the presence of high supercooled liquid water contents (> 0.1 g kg^{-1}) can present an aviation hazard. Secondly, thin but extensive layers of supercooled liquid water (typcially of optical depths around 3 but of water content only 0.01 g kg^{-1}) can have a large effect on the radiation in the system.

iii) Cloud fraction: The volume cloud fraction is the fractional volume of a well defined grid box which contains condensate. The area cloud fraction is the fractional area of a well defined gridbox which contains some condensate when viewed from above. The fraction of a model gridbox covered by cloud is of major interest to modellers, since this strongly effects the radiation profile in the atmosphere and also the precipitation characteristics. Also important is the way in which this cloud is correlated in the vertical, as this also affects its radiation characteristics.

iv) Ice particle distributions: The number density of ice particles for a given range of (unmelted) maximum ice particle diameters. The particle size distribution of ice particles is parametrized within radiation and precipitation schemes. Observations may allow more realistic parametrizations to be developed. Such measures as effective radius and particle concentration are important. Although aircraft data can measure complete distributions, only nearly-continuous sampling methods can obtain enough statistics to fully assess these distributions across the wide variety of weather types which occur.

v) Liquid particle distributions: The number density of liquid droplets for a given range of equivolume spherical diameters. This is for similar reasons as ice particle distributions.

vi) Ice fall speeds. Ice fall speeds influence the microphysical evolution of a cloud, and the ice water content. This strongly alters its precipitation and radiation characteristics. Ice fall speeds are an effective way to tune climate models. Therefore better measurements can physically constrain the representation of fall speeds within models. The information on fall speeds would be useful in many forms, such as an ice content - masss weighted mean fall speed relationship, or an ice content - mean particle size relationship.

3. COMPARISON OF MODEL AND OBSERVATIONAL DATA.

Computer simulations and observations do not generally measure the same quantity. Assumptions are required to transform between the two. These assumptions may have already been used within a particular model simulation, in which case a fair comparison may be performed in observational space, but this is not generally the case.

To transform from model to observation space does not necessarily require the same set of assumptions as a transform from observation to model space. For example, if two model variables are required to calculate one observational quantity, observation of that single quantity is not sufficient to retrieve the two model variables, without an additional assumption.

Model formulations may change during the lifetime of CloudNet, which could mean a continuous conversion to observational fields could be awkward. If the observational sites change specification, then the reverse is also true.

Representivity is also an important consideration, since the model is producing gridbox mean variables and the radar sites providing much smaller scale measurements. Averaging the observations or the simulated model fields is required, taking care that the averaging method does not bias the result. It is important that the sampling time is sufficient to capture the variability in the cloud fields at a particular location. A model sampling time of one hour may not capture the full range of clouds which were forecast within the proceeding hour. Observations, even if averaged over time, will only sample a small fraction of a model grid box since advection of the cloud field over the observing site will only record data from one horizontal dimension, rather than two.

There is an additional complication if there are several models or observational specifications in the comparison, because there would be separate algorithms required to transform between any pair of models or sites. It is then better to transform the data from *all* the models and observational sites to a precisely specified variable. An example would be ice water content. The important issue is to precisely define the quantity where comparison is being made. However, all the observational sites would then require slightly different algorithms to make the transform because the information available at each site is different. (The models would also require slightly different algorithms, because one model may, for example, split ice into several categories).

a) Recommended Space for Model - Observational Comparisons.

We therefore recommend that models and observations produce processed data that correspond to well defined quantities. These quantities will be different for models and observations. For example, the model might produce the quantity of `ice water content at the end of the model timestep' and the observations '94 GHz reflectivity'. All models would produce the same set of well-defined quantities. All observational sites would produce the same set of well defined quantities*. Following discussion with the CloudNet community, these will be:*

i) 35 GHz reflectivity, Doppler velocity and Doppler width
ii) 94 GHz reflectivity, Doppler velocity and Doppler width
iii) Lidar backscatter and cloud base
iv) Liquid water path direct from radiometers
v) Broadband radiation
vi) Rainrates.

These measurements will be provided as calibrated with an estimate ofthe error on the measurement. It would then be a part of CloudNet to develop algorithms to transform from one set of well-defined quantities to the other. The same algorithms would apply for every model and radar comparison. It is likely that the best algorithms to transform in each direction are not inverses of each other, and therefore that the error in using the transform in one direction is larger than the error in transforming the other way. Only after the algorithms have been determined is it likely that we can answer the question of which comparison space has the least error, so comparison may be best investigated both in observation and model space.

Please refer to the attached power point slides for a visual demonstration of the above process.

There is also potentially useful information available even if the conversion between two quantities is very difficult. This is the case if there are gross differences between the models and observations. One example would be if the observations detected no clouds throughout a lengthy averaging period during a particular meteorological situation, yet the models predicted a large cloud water content even though it predicted the same meteorological situation. If representivity problems are identified as small, then it is possible that a model error could then be identified and perhaps understood without quantitative comparison with observations.

The initial comparison of data from the models and observations may be best carried out in this way.

b) Comparison Strategies.

The two main strategies for comparison are climatology and case studies.
i) ‘Climatological comparison’ compares time averaged model fields with time averaged observational fields for a given sampling period. This reduces sensitivity to random aspects of initial condition errors. Concurrent observing and modelling will ensure that the uncertainty due to natural variability is minimised, and the three stations reduces the possibilities that local effects are significant.
ii) ‘Regime comparison’ conditionally samples the climatological data according to a particular criterion, such as mid-tropospheric vertical velocity. This allows a closer look as to why the overall climatology may show errors that are dependant on flow regime.
iii) Case study comparison allows a more direct link between errors in model predictions and errors in the model. The spatial distribution of parameters within a cloud can be studied. However, it is necessary to apply dynamical and thermodynamical forcing as accurately as possible, since this almost uniquely determines the resulting cloud regime.
iv) Variability. The high time resolution data from CloudNet could be used to look at the variability and higher order moments of moisture, cloud and temperature quantities within a gridbox, which relate to important assumptions or parametrizations which occur within large-scale models.

4. ERRORS.

It is one of the objectives of CloudNet to assess the reasons why forecasts and observations do not agree. These differences arise from model errors, observational errors and transform errors. One can consider the combined error for each comparison to be the difference between what the model predicted and what was observed. (What really happened, or ‘truth’, always remains unknown). It is vital to assess the full range of errors in a model - observational comparison.

a) Model errors (compared to truth):

These arise from two different sources.
i) the initial conditions
ii) the forward NWP model (i.e. the dynamics and physics parametrizations) used to make the forecast.
Since data assimilation techniques use the model in their formulation, errors in the two sources are related to each other. By looking at many cases, or by comparing case studies by dynamic regime, *random* errors in i) should be minimized. However, there may be *biases* present. Comparisons of model and observations at analysis time, or within the ‘spin-up’ time, will quantify the degree of bias present in the analysis. The cause of these biases may lie in either the use of observational and background data by the models or the forward NWP model. Comparisons of biases at longer lead times, where the model is free to achieve its own balance between variables independent of constraints from the assimilation scheme, will better show errors produced by the forward NWP model only.
Random and bias errors may involve timing or spatial displacement errors, as well errors in the magnitudes of quantities such as ice water content or cloud fraction.

b) Observational errors (compared to truth):

i) These are due to inaccurate measurement or estimation of a quantity

c) Transform errors (compared to truth):

i) The error or uncertainty in the method used to transform from observed quantities to the model space, or vice versa.
ii) Representivity error, if the observations and models refer to different scales.
Characterization of errors is therefore of high priority in algorithm development.

d) Consistent processing of data.

It is possible that biases can occur when processing model and observational data, even in the same way. For example, if one processes data to remove points where the rainfall rate is greater than a certain threshold. Although this is a well defined method of choosing points, a comparison against model data similarly filtered requires that the model has the same distribution of rainfall rates as the observations. Otherwise the rejection of data has a bias between models and observations. Care must be taken to quantify such errors in processing.

5. DATA FORMATS.

It is important that all the models (and the same applies to observations) have the same data format to allow easy comparison between models. At the present time the Meteo-France model and the ECMWF model have a very similar, but not identical, data format. This does not require that time and space resolution needs to be the same, simply that the format needs to be identical.

6. SUMMARY

Large-scale models are formulated using prognostic fields defined on grids with horizontal sizes typically of 10's of kilometres. Processes which determine the evolution of the prognostic variables are parametrized, and other variables (if the model requires them) are determined by diagnostic parametrizations from the prognostic variables.
Key fields to verify are ice and liquid water contents and cloud fractions. Microphysical and dynamical information is also useful, but not as fundamental to the models.
Models should concentrate on providing data for the same set of well-defined quantities, and similarly for observations, using a different set of well-defined quantities.
CloudNet will then develop algorithms to transform between the two sets.
Comparisons will be performed in model or observation space, whichever the person doing the comparison feels is most appropriate.
The overhead for comparing several models with several observing sites is little more than that for a single model and single site.
It is vitally important that errors in all stages of the comparison process are assessed and documented.

a) Recommendations for CloudNet.

i) It is essential that error estimates are provided with the processed data. Any aspects of the data which are particularly suspect and require advice from the originators of the data shall be flagged as such. For example, data may be suitable for use for one retrieval, but not another. If suspect data is not flagged users will

assume that the data is safe to use for whatever application they see fit.
ii) Models should all produce data for an agreed list of well-defined quantities, as indicated in section 2. Observation sites should all produce data for an agreed list of well-defined quantities, as indicated in section 3.
iii) Algorithms shall be developed to transform between the sets of model and observation quantities indentified in sections 2 and 3.
iv) Where it is possible (i.e. without more assumptions than already used within the model), models shall provide enough details on algorithms to enable their fields to be converted directly to the equivalent of observations. This would require a sensitivity analysis of the assumptions to quantify the error introduced in transforming between variables.
v) Data from each CloudNet site and model shall be stored in a way which is accessible to all of the CloudNet partners and to allow straightforward comparison. The data shall be fully documented. Documentation shall include the precise specification of the locations of gridboxes in time and space.
vi) Data formats should be the same for all models, and for all observations. The data grids need not be the same.
vii) Users are unlikely to need access to unprocessed measurements (such as raw, uncalibrated values of reflectivity contaminated by clutter etc.)
viii) For the development of climatology, observational sampling should not biased with respect to the weather conditions. Where sampling is biased, assessments shall be made to quantitatively estimate the impact of the bias.

7. ANNEXE

Please see the associated Power Point demonstration that accompanies section 3.

8. ACKNOWLEDGEMENTS

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