Numerical Weather Prediction
Parametrization of sub-grid physical processes

Clouds (4)
Cloud Scheme Validation

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(with thanks to Adrian Tompkins and Christian Jakob)
Today’s lecture will discuss:

• Different observation types for model cloud evaluation
• Different evaluation methodologies to inform parametrization development
• Limitations of model evaluation due to uncertainties and differences in observed and modelled quantities

Two parts:

1. Methodologies for diagnosing model errors
2. Evaluation uncertainties and limitations
Cloud Validation: The issues

- **AIM**: To perfectly simulate one aspect of nature: CLOUDS
- **APPROACH**: Validate the model generated clouds against observations, and use the information concerning apparent errors to improve the model physics, and subsequently the cloud simulation.

Sounds easy?
Cloud Validation: The problems

- How much of the ‘error’ derives from observations?

Cloud observations error = $\varepsilon_1$

Cloud simulation error = $\varepsilon_2$

Error

Parametrization improvements
Cloud Validation: The problems

- Which Physics is responsible for the error?

Cloud observations → Error → Parametrization improvements

Cloud simulation

- radiation
- turbulence
- cloud physics
- convection
- dynamics
The path to improved cloud parametrization...
1. Methodology for diagnosing errors and improving parametrizations
Cloud Validation: The problems

1. Methodology

Cloud observations

Cloud simulation

Error

Parametrization improvements

Cloud physics

Radiation

Convection

Turbulence

Dynamics
A strategy for cloud parametrization evaluation

From C. Jakob

- For example, systematic errors in radiation, cloud cover, precipitation...
- Use long timeseries of observational data (satellite, ground-based profile, NWP verification)
- Statistical evaluation (mean, PDFs)
- Short-range forecasts or model climate (multi-year simulations)
Model climate: Broadband radiative fluxes

Can compare Top of Atmosphere (TOA) radiative fluxes with satellite observations: e.g. Example of TOA Shortwave radiation (TSR) from an old version of the model (operational in 1998!)

Stratocumulus regions bad - also North Africa (old cycle!)
Model climate: Cloud radiative “forcing”

- **Problem**: Can we associate these “errors” with clouds?
- **We can look at** “cloud radiative forcing” (calculate radiative impact of cloud by comparing cloudy points with clear sky points)

Cloud Problems: strato-cu **YES**, North Africa **NO**!

Note: blanked out areas are where there are not enough clear sky points in the obs
Model climate
“Cloud fraction” or “Total cloud cover”

Can also compare other variables to derived products: CC

References: ISCCP - Rossow and Schiffer, Bull Am Met Soc. 91,
ERBE - Ramanathan et al. Science 89
Model climate mean differences

Model T159 L91

More recent cycle!

CERES satellite obs

Top-of-atmos net SW radiation 1-year average

Difference

albedo high

albedo low
Model climate mean differences

Model T159
L91

Total Cloud Cover (TCC) 1-year average

ISCCP satellite obs

TCC high
TCC low

Difference
Model climate mean differences

Model T159
L91

SSMI satellite obs

Total Column Liquid Water (TCLW) 1-year average

Difference

high
low
Model climate mean differences

T159 IFS – Obs differences 1-year average

Correlations not always so clear! Need additional info to understand systematic errors

albedo high
net TOA SW
albedo low

Cloud cover

high
low

Liquid water path

high
low
Network of stations providing profile data for multi-year period

“CloudNet” project (www.cloud-net.org) “ACTRIS” is follow-on: European multi-site data processing using identical algorithms for model evaluation.

“FASTER” project (faster.arm.gov) processing for global observation sites from the ARM programme (currently active).
“Permanent” ARM sites and movable “ARM mobile facilities” for observational campaigns (www.arm.gov)

Note for 2015: Azores now fixed site, Tropical fixed sites now closed
Cloud fraction
Chilbolton Observations

Met Office Mesoscale Model

ECMWF Global Model

Meteo-France ARPEGE Model

KNMI RACMO Model

Swedish RCA model
Statistical evaluation: CloudNet Example

• In addition to standard quicklooks, longer-term statistics are available.

• This example is for ECMWF cloud cover during June 2005.

• Includes pre-processing to account for radar attenuation and snow.

• See www.cloud-net.org for more details and examples!
Statistical evaluation:
Short-range NWP versus long-range “climate”

- Differences in longer simulations may not be the direct result of the cloud scheme:
  - Interaction with radiation, dynamics etc.
  - E.g: poor stratocumulus regions

- Using short-term NWP or analysis restricts this and allows one to concentrate on the cloud scheme

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Cloud cover bias vs Synops
Example over Europe
Bias of 48 hour forecast cloud cover vs Synop

![Map showing cloud cover bias over Europe with data points indicating the bias and total cloud cover. The map is labeled with latitude and longitude lines, and icons denote areas with different cloud cover biases.]
“Going more into details of the cyclone, it can be seen that the model was able to reproduce the very peculiar spiral structure in the clouds bands. However large differences can be noticed further east, in the warm sector of the frontal system attached to the cyclone, where the model largely underpredicts the typical high-cloud shield. Look for example in the two maps above where a clear deficiency of cloud cover is evident in the model generated satellite images north of the Black Sea. In this case this was systematic over different forecasts.” – Quote from ECMWF daily report 11th April 2005
NWP Forecast Evaluation
Identifying the cause of cloud errors?

Daily Report 11th April 2005
Meteosat and simulated WV example

Blue: moist
Red: Dry

30 hr forecast too dry in front region.
So maybe another cause, not the cloud scheme itself.
Identifying major problem areas

- Need to evaluate the model from many different viewpoints to identify which problems are associated with cloud.

- Evaluate the statistics of the model (mean, pdf, …) - long timeseries of data.

- Use of long forecasts (climate) and short forecasts (to avoid climate interactions and feedbacks).

- Use of data assimilation increments, initial tendencies.
A strategy for cloud parametrization evaluation: Composites

Step 1: identify major problem areas
Step 2: identify major problem regimes
Step 3: identify typical case
Step 4: identify detailed problems
Step 5: improve parametrization
Isolating the source of error

- We want to isolate the sources of error. Focus on particular phenomena/regimes, e.g.
  - Extra tropical cyclones
  - Stratocumulus regions
- An individual case may not be conclusive: Is it typical?
- On the other hand general statistics may swamp this kind of system.
- Can use compositing technique (e.g. extra-tropical cyclones).
- Focus on distinct regimes if can isolate (e.g. Stratocumulus, Trade Cumulus).
Composites – Extra-tropical cyclones

Overlay about 1000 cyclones, defined about a location of maximum optical thickness

Plot predominant cloud types by looking at anomalies from 5-day average

- High Clouds too thin
- Low clouds too thick

High tops=Red  Mid tops=Yellow  Low tops=Blue

Klein and Jakob, 1999, MWR
Model Climate: Regime dependent error?

TOA net SW radiation vs. CERES:
Too much reflectance from TCu, not enough from Sc

Maike Ahlgrimm
Does the model have “correct” trade cumulus cloudiness?

Three aspects:

Cloud amount when present (AWP)

helps identify cloud type

Cloud frequency of occurrence (FOO)

with amount when present (AWP) gives total cloud cover

Radiative properties

radiative balance ultimately drives the system

Maike Ahlgrimm
Identify cloud samples as:
• with less than 50% cloud fraction
• cloud top below 4km
• over ocean
• between 30S and 30N
TCu frequency of occurrence (FOO)

CALIPSO frequency of occurrence of TCu samples 46.5%

CY31R1 frequency of occurrence of TCu samples 70.8%

Model has TCu more frequently than observed

Ahlgrimm and Köhler, MWR 2010
Smaller cloud fractions partially compensate for the overprediction of frequency of cloud occurrence, but still overall cloud fraction from trade cumulus is too large – too reflecting – short wave bias?

Most of the additional TCu samples have very small cloud fractions

Ahlgrimm and Köhler, MWR 2010
A strategy for cloud parametrization evaluation

1. Step 1: identify major problem areas
2. Step 2: identify major problem regimes
3. Step 3: identify typical case
4. Step 4: identify detailed problems
5. Step 5: improve parametrization
Case Studies

• Can concentrate on a particular location and/or time period in more detail, for which specific observational data is collected:

CASE STUDY

• Examples:
  – GATE, CEPEX, TOGA-COARE, ARM, TWP-ICE, ASCOS, M-PACE,…
GEWEX Cloud System Study
(now GASS, gewex.org)
(Moncrieff et al. Bull. AMS 97)

**Step 1**
Use observations to evaluate parameterizations of subgrid-scale processes in a CRM

**Step 2**
Evaluate CRM results against observational datasets

**Step 3**
Use CRM to simulate precipitating cloud systems forced by large-scale observations

**Step 4**
Evaluate and improve SCMs by comparing to observations and CRM diagnostics
Figure 7. Vertical profiles of the total cloud condensate (liquid + solid) for simulations by different single-column models (see Tables 1 and 2 for explanations of the acronyms).
Summary

• **Long term statistics:**
  – Climate systematic errors – we want to improve the basic state/climatology of the model
  – But which physics is responsible for the errors? Non-linear interactions.
  – Long term response vs. transient response.

• **Isolating regimes:**
  – Composites and focus on geographical regions.

• **Case studies**
  – Detailed studies with Single Column Models, Cloud Resolving Models, NWP models
  – Easier to explore parameter space.
  – Are they representative? Do changes translate into global skill?
2. Comparing model and obs: Uncertainty and limitations
2. Uncertainty

Cloud Validation: The problems

Cloud observations

Cloud simulation

Error

Parametrisation improvements

radiation

cloud physics

convection

turbulence

dynamics

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What is a cloud?
Models and observations

What is a cloud?

- Different observational instruments will detect different characteristics of clouds.
- A cloud from observations may be different to the representation in models.

- Understanding the limitations of different instruments
- Benefit of observations from different sources
- Comparing like-with-like (physical quantity, resolution)
Verification
Uncertainty in quantities derived from observations...

Widely varying estimates of IWP from different satellite datasets!

Cloud Sat
(From Waliser et al 2009)
What is being compared?
Cloud ice vs. snow – comparing like-with like

Model Ice Water Path (IWP) (1 year climate)

IWP from prognostic cloud ice variable

IWP from cloud ice + precipitating snow

Observed Ice Water Path (IWP)
CloudSat 1 year climatology
Hogan et al. (2001)

Comparison improved when:

(a) snow was included,

(b) cloud below the sensitivity of the instruments was removed.
Space-borne active remote sensing
A-Train

- CloudSat and CALIPSO have active radar and lidar to provide information on the vertical profile of clouds and precipitation. (Launched 28th April 2006)

- Approaches to model validation:
  
  - Model → Obs parameters
  - Obs → Model parameters

- Spatial/temporal mismatch
Simulating Observations
CFMIP COSP radar/lidar simulator

Model Data (T,p,q,iwc,lwc...)

Sub-grid Cloud/Precip Pre-processor

Physical Assumptions (PSDs, Mie tables...)

CloudSat simulator (Haynes et al. 2007)

CALIPSO simulator (Chiriaco et al. 2006)

Radar Reflectivity

Lidar Attenuated Backscatter

http://cfmip.metoffice.com

Note: COSP now has many more satellite simulators
Example cross-section through a front
Model vs CloudSat radar reflectivity
Radar Reflectivity
Along-track model vs. CloudSat animation
Example CloudSat orbit “quicklook”
http://www.cloudsat.cira.colostate.edu/dpcstatusQL.php
Example section of a CloudSat orbit
26th February 2006  15 UTC

Mid-latitude cyclone

High tropical cirrus

Mid-latitude cyclone
Compare model with observed parameters: Radar reflectivity

Simulated radar reflectivity from the model for ice only (< 0° C)

Observed radar reflectivity from CloudSat (ice + rain)
Compare model parameters with equivalent derived from observations: Ice Amount

Model ice water content (excluding precipitating snow).

Ice water content derived from a 1DVAR retrieval of CloudSat/CALIPSO/Aqua

(Delanöe and Hogan (2007), Reading Univ., UK)
Spatial resolution mis-match

- Need to address mismatch in spatial scales in model (50 km) and obs (1 km)
- Sub-grid variability is predicted by the IFS model in terms of a cloud fraction and assumes a vertical overlap.
- Either:
  1. Average obs to model representative spatial scale
  2. Statistically represent model sub-gridscale variability using a Monte-Carlo multi-independent column approach.
When comparing a model with observations, we need to compare like-with-like.
Model validation
Making the most of instrument synergy

• Observational instruments measure one aspect of the atmosphere.

• Often, combining information from different instruments can provide complementary information (particularly for remote sensing)

• For example, radars at different wavelengths, lidar, radiometers.

• CloudSat/CALIPSO
Example of mid-Pacific convection

CloudSat radar
Deep convection penetrated only by radar

CALIPSO lidar
Cirrus detected only by lidar
Mid-level liquid clouds

Julien Delanoë/Robin Hogan
Combining radar and lidar using a variational technique (Delanoë and Hogan 2010)

Cloudsat radar

CALIPSO lidar

Preliminary target classification

Global-mean cloud fraction

Radar misses a significant amount of ice

Radar and lidar

Radar only

Lidar only

Julien Delanoë/Robin Hogan
Summary

• Different approaches to verification (climate statistics, case studies, composites), different techniques (model-to-obs, obs-to-model) and a range of observations are required to validate and improve cloud parametrizations.

• Need to understand the limitations of observational data. Ensure we are comparing like with like. Use complementary observations - synergy.

• The model developer needs to understand physical processes to improve the model. Requires, theory and modelling and novel techniques for extracting information from observations.
The path to improved cloud parametrization...

Many mountains to climb!

- Cloud validation
- Case studies
- Composite studies
- Parametrization improvement
- NWP validation
- Climatological comparison