云和对流参数化简介

地球系统科学前沿讲座

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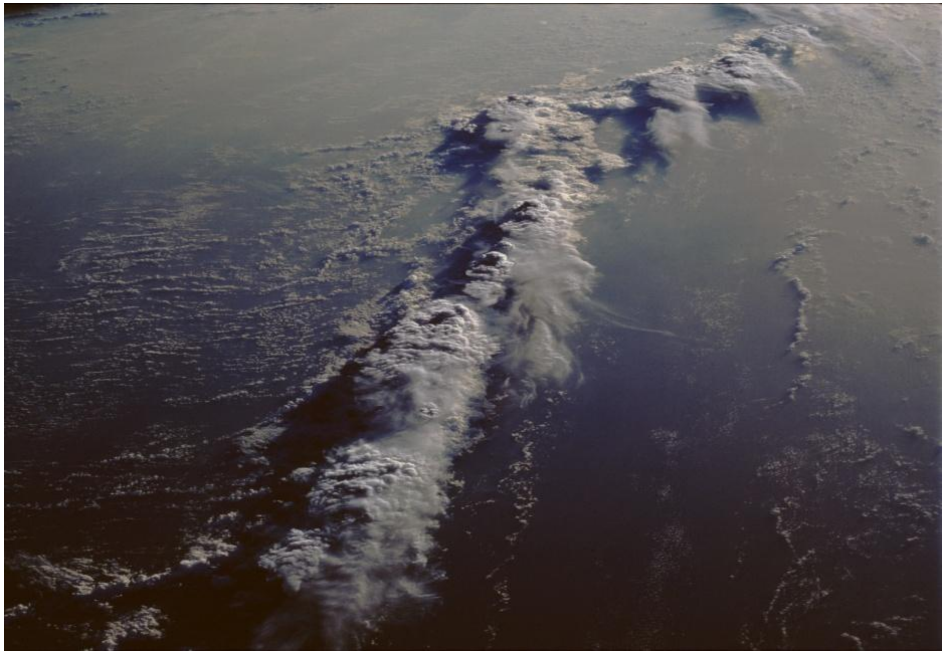
2012.9.24

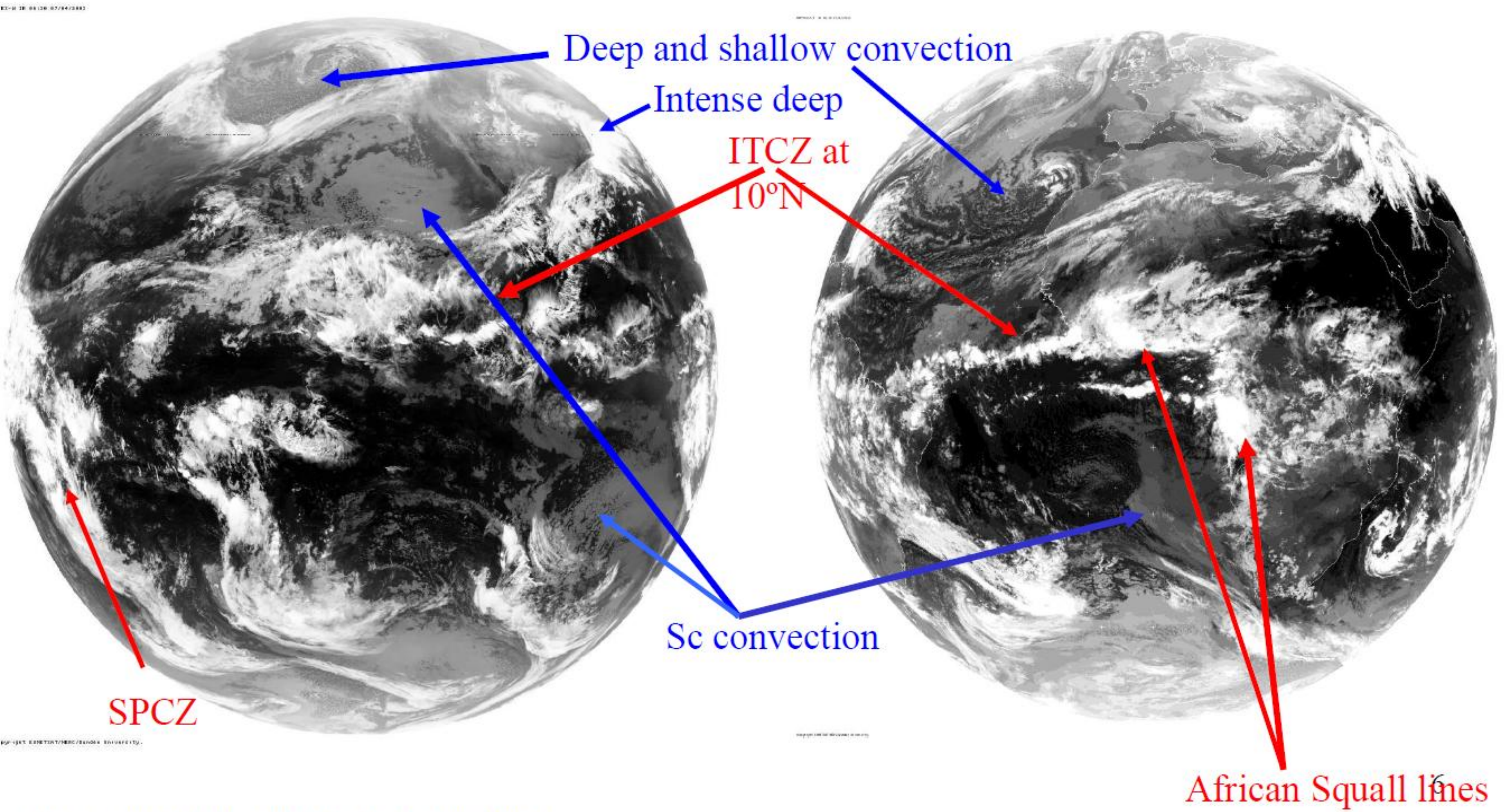
Outline

- What is cloud? What is convection? what is parameterization?
- Why we need cloud and convection parameterization?
- What are cloud and convection parameterizations?
- A brief history and some examples
- Current status and future

What is cloud?



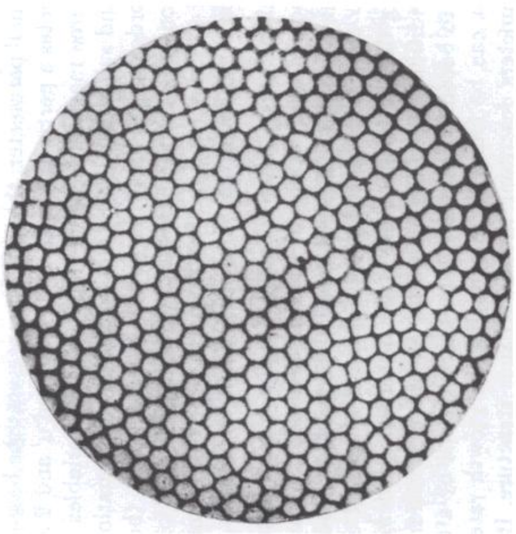
What is convection?

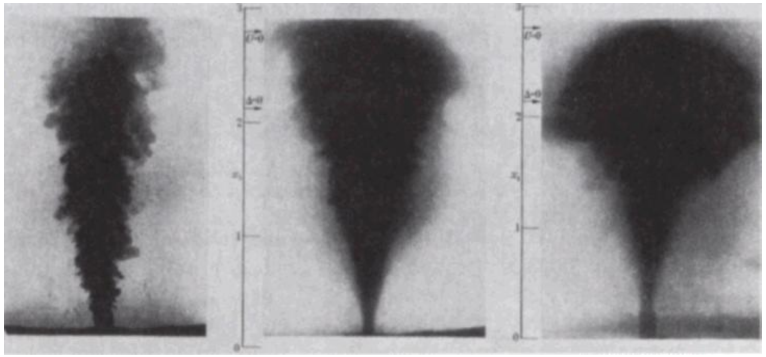


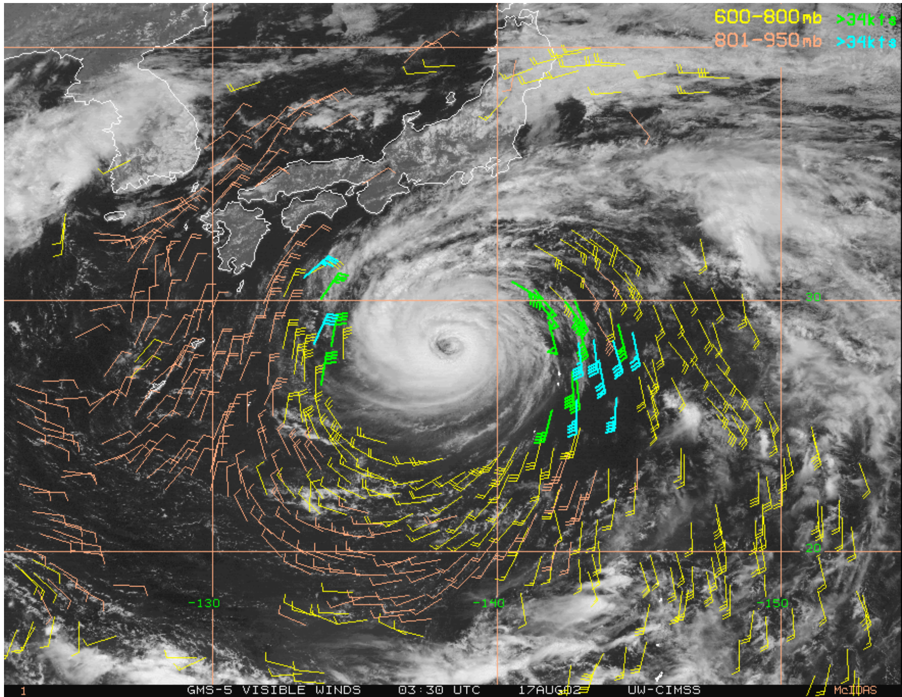
IR GOES METEOSAT 7/04/2003

From Peter Bechtold ECMWF

How does it look like ?







What is parameterization?

A “parameterization” is designed to represent the effects of the smaller-scale processes (turbulence, cloud microphysics, convection, etc.) in terms of the large-scale state (u,v,w,T,q,p).

Predict Temperature change at Beijing

$$\frac{\partial \overline{s}}{\partial t} + \overline{\vec{v}}_h \nabla \overline{s} + \overline{\omega} \frac{\partial \overline{s}}{\partial p} = \underbrace{\overline{Q}_R + L(\overline{c} - \overline{e}) - \frac{\partial \overline{\omega' s'}}{\partial p}}$$

"large-scale observable" terms "sub-grid" terms

All because of scale (time and spatial scale)

- Molecular scale→ particle scale → parcel scale → cloud scale
- Cloud scale (shallow cumulus ~100 m)→deep cumulonimbus (~1km) → thunder storm (~10km) →mesoscale convective complex (~100km).

Cumulus parameterization

Tasks of convective parameterization

Determine occurrence/localisation of convection

→ Trigger

Determine vertical distribution of heating, moistening and momentum changes

→ Cloud model

Determine the overall amount of the energy conversion, convective precipitation, heat release

→ Closure

History and basic ideas

- **Moisture budget** (Guo 1965, 1974)

- **Adjustment scheme**

Moist convective adjustment (Manabe, 1965)
Penetrative adjustment scheme (Betts and Miller 1974)

- **Mass flux schemes** (spectral/bulk)

Arakawa and Schubert 1974,
Kain and Fritsch 1993
Emanuel 1991,

- **Some new ideas**:

buoyancy sorting, stochastic, memory, ‘org’, EDMF

Quasi-equilibrium hypothesis

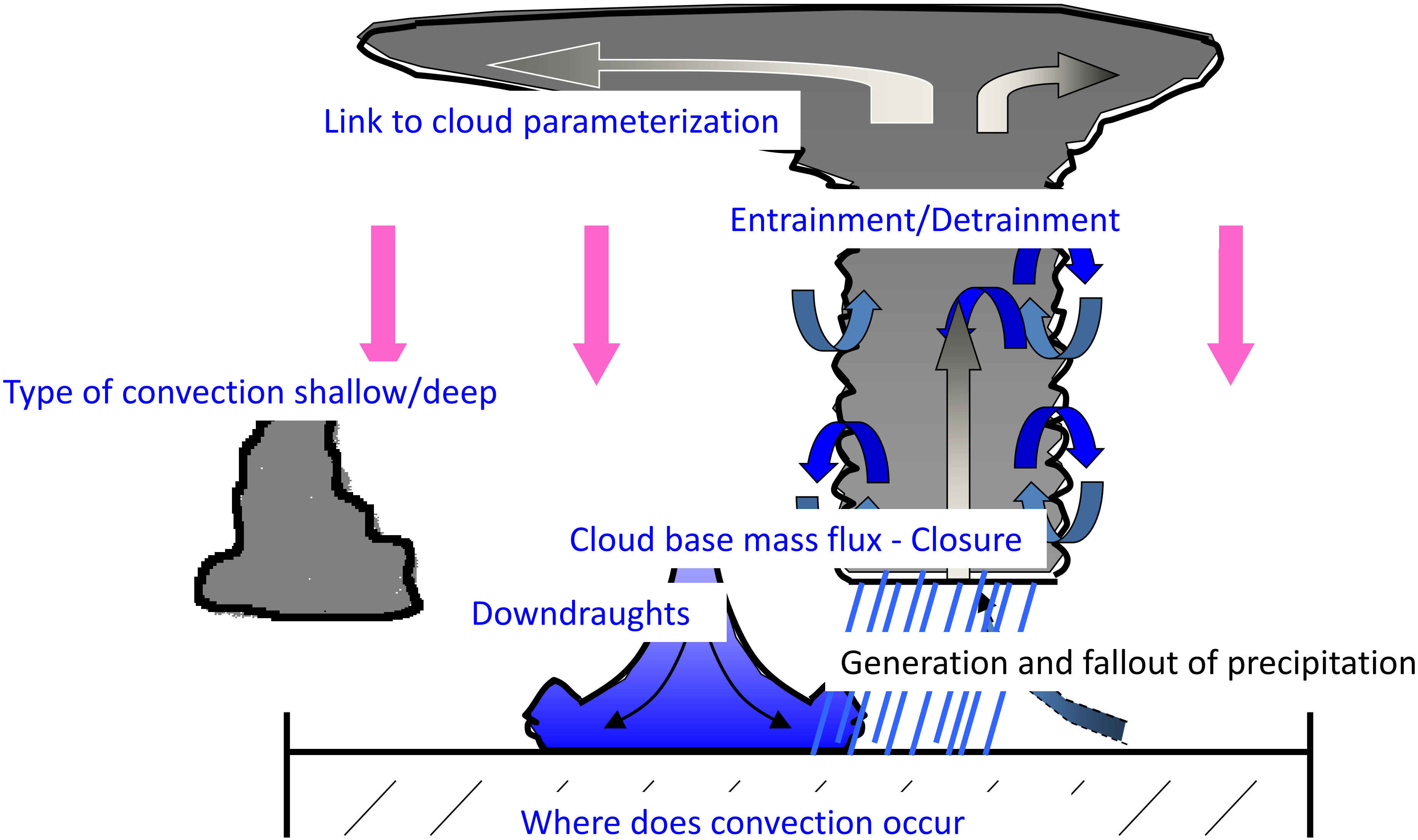
- Arakawa and Schubert (1974) postulated that the level of activity of convection is such that their stabilizing effect balances the destabilization by large-scale processes.

A wealth of exploration

- Emanuel, 1994: Atmospheric convection, *OUP*
- Emanuel and Raymond, 1993: The representation of cumulus convection in numerical models. *AMS Meteor. Monogr*.
- Smith, 1997: The physics and parametrization of moist atmospheric convection. *Kluwer*
- ……

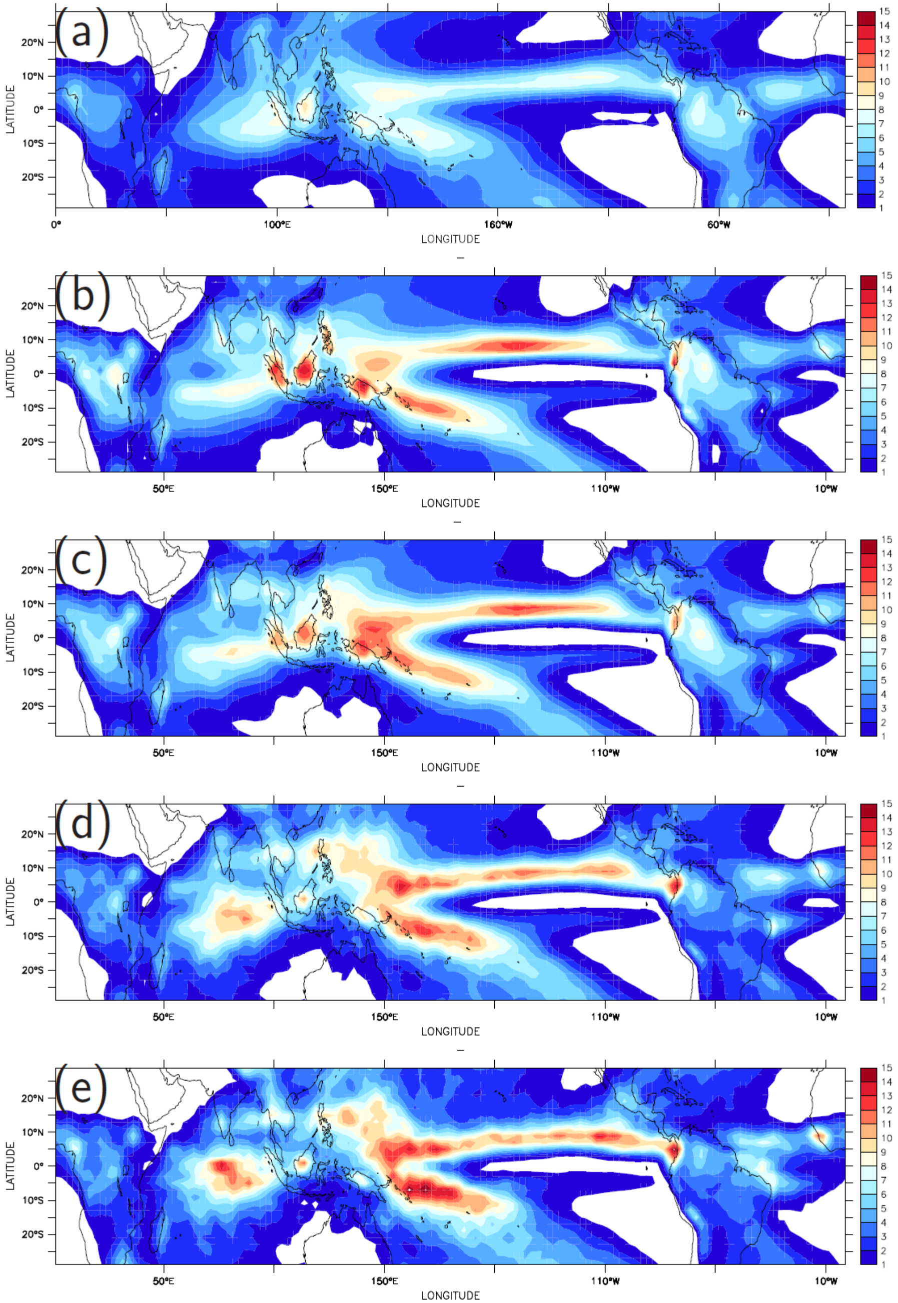
A bulk mass flux scheme: plume model

What needs to be considered



Bechtold, ECMWF

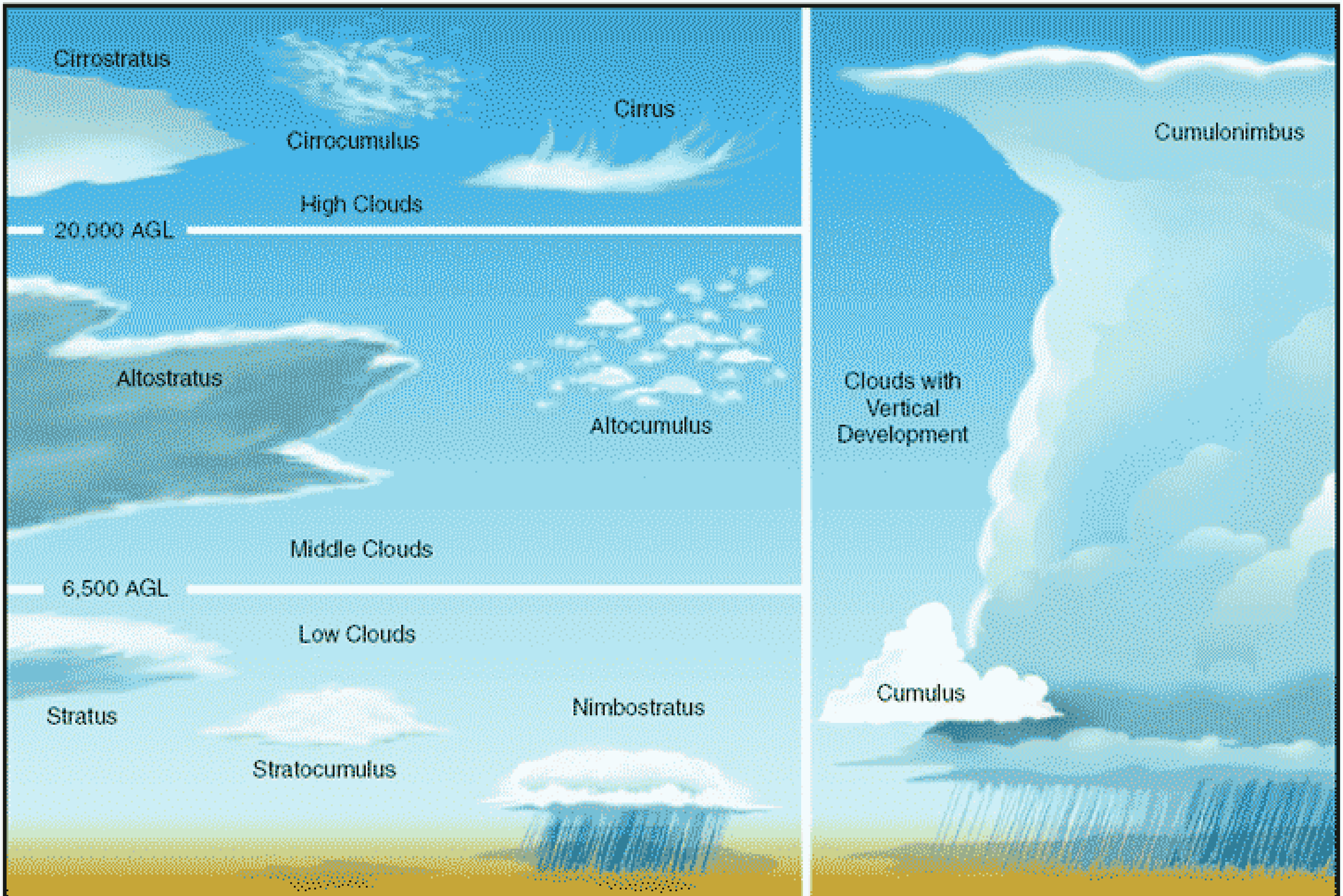
Impact of Cu on GCM (GFDL AM2)



A single parameter change in the RAS scheme induces huge change of global mean precipitation

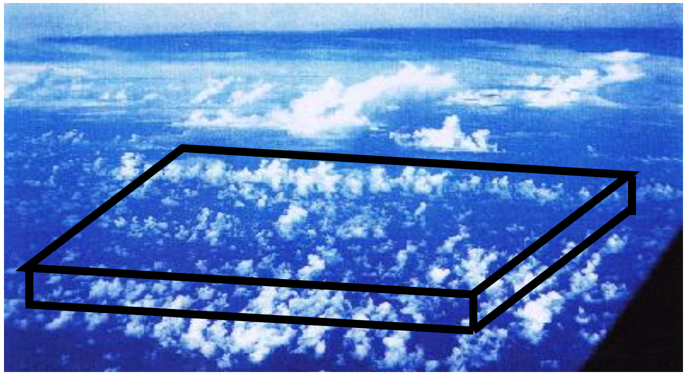
Lin et al. 2012

Cloud parameterization

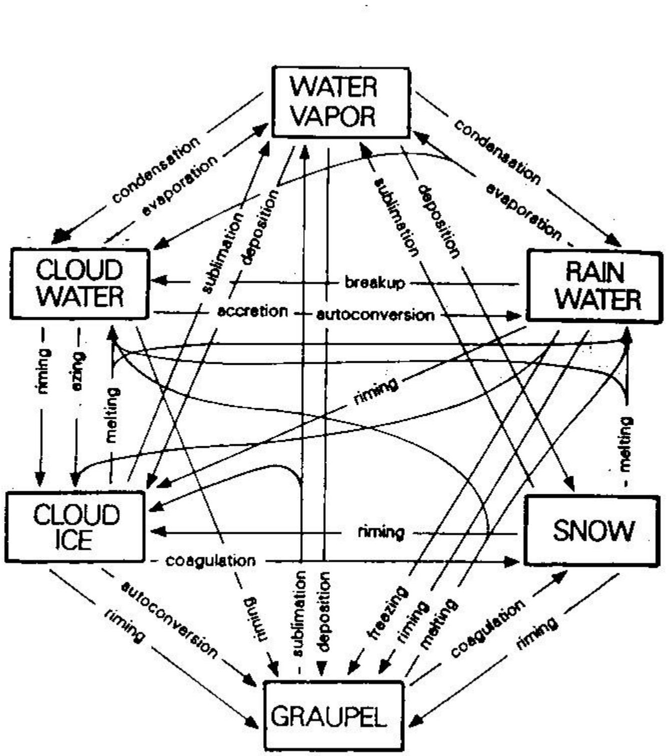


Cloud parameterization

- Cloud macrophysics (subgrid variability, qa)



- Cloud microphysics (phase change, particle collision, fallout, etc.)



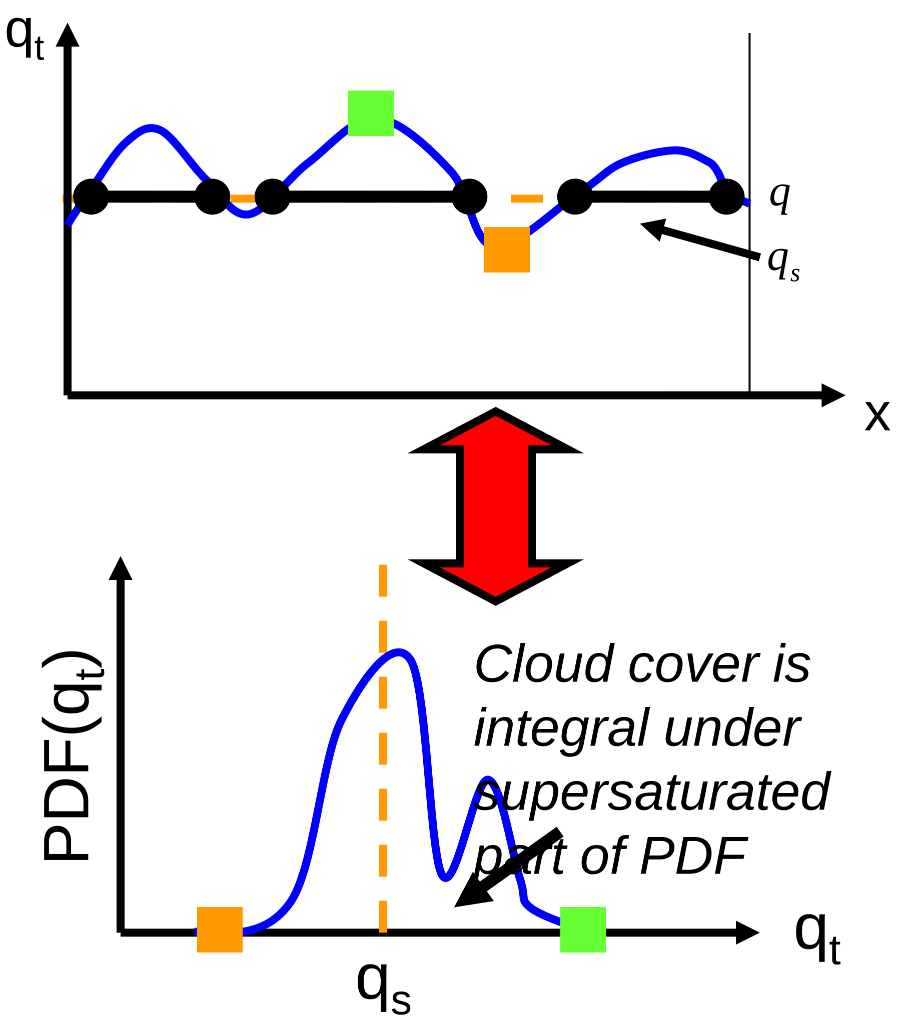
Cloud fraction

- Diagnostic method: F(RH,w,…)
- Sundqvist et al. 1989 $$C = 1 - \sqrt{\frac{1 - RH}{1 - RH_{crit}}}$$
- Xu and Randall 1996 C = F(RH,qc)
- *"Given a RH of X% in nature, the mean distribution of q_t is such that, on average, we expect a cloud cover of Y%".*

- Prognostic method:

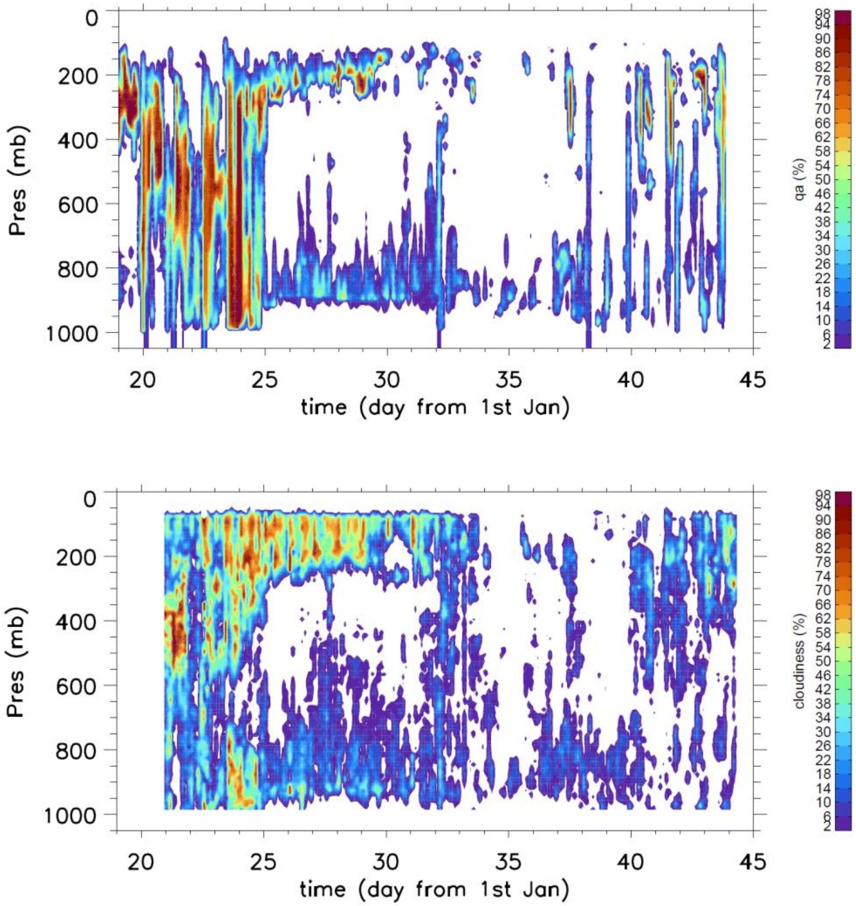
Statistical Schemes (prognostic)

- These explicitly specify the probability density function (PDF) for the total water q_t (and sometimes also temperature)



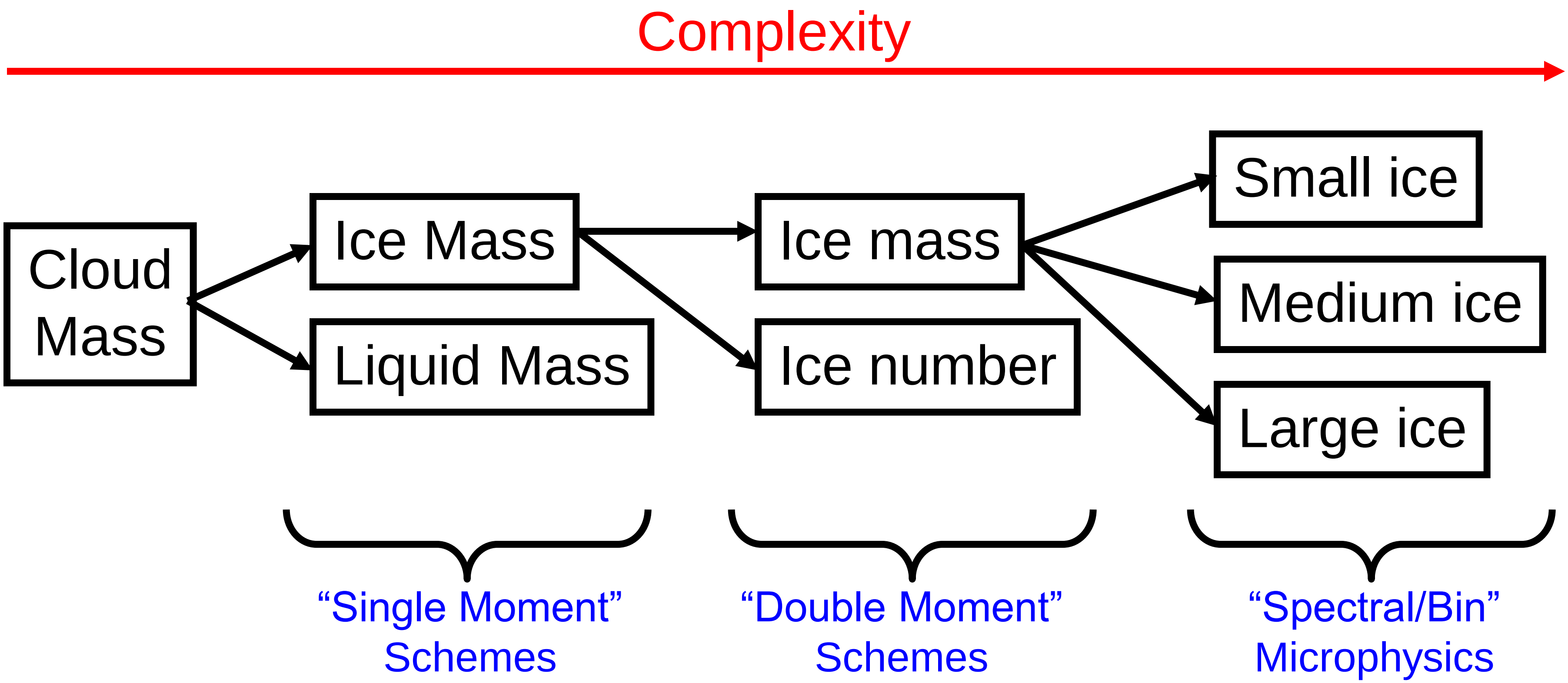
A simple diagnostic qa scheme

- Assuming normal distribution of qv with fixed T.
- Relate variance to other physical processes (PBL, convection, background variability)



Lin et al. 2012

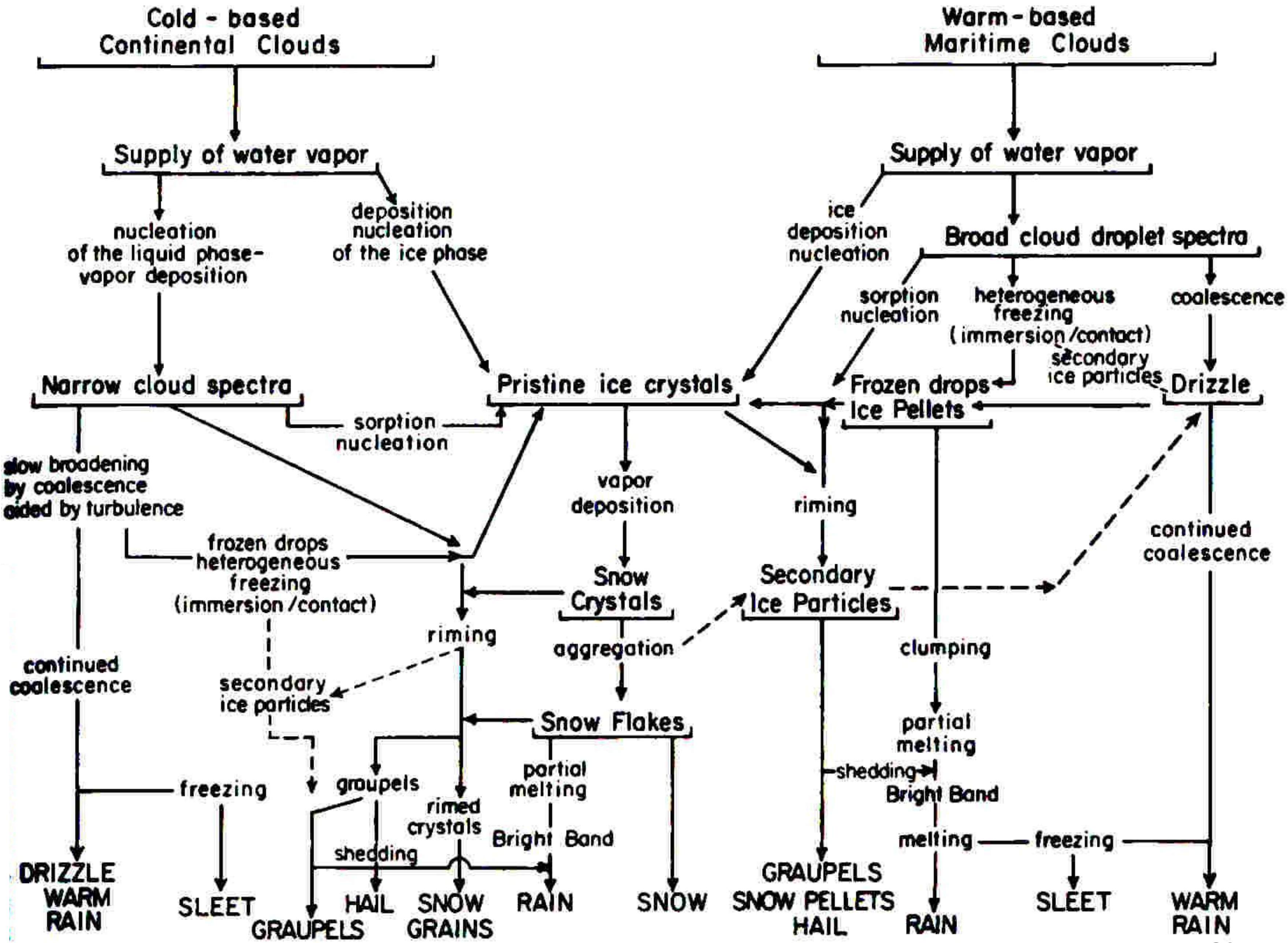
Cloud Parametrization Issues:
Complexity ?



Most GCMs only have simple single-moment schemes

Cloud microphysical processes

- We would like to include in our models:
  - Formation of clouds
  - Release of precipitation
  - Evaporation of both clouds and precipitation
- Therefore we need to describe
  - Nucleation of water droplets and ice crystals from water vapour
  - Diffusional growth of cloud droplets (condensation) and ice crystals (deposition)
  - Collection processes for cloud drops (collision-coalescence), ice crystals (aggregation) and ice and liquid (riming) leading to precipitation sized particles
  - The advection and sedimentation (falling) of particles
  - the evaporation/sublimation/melting of cloud and precipitation size particles

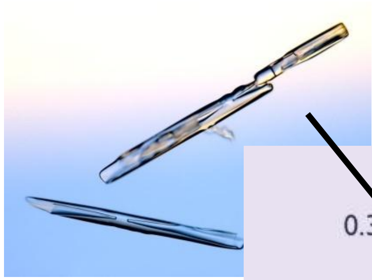


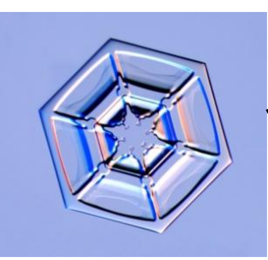
Cold - based Continental Clouds
Warm - based Maritime Clouds
Supply of water vapor
Supply of water vapor
nucleation of the liquid phase-vapor deposition
deposition nucleation of the ice phase
ice deposition nucleation
Broad cloud droplet spectra
sorption nucleation
heterogeneous freezing (immersion /contact)
coalescence
secondary ice particles
Narrow cloud spectra
Pristine ice crystals
Frozen drops Ice Pellets
Drizzle
sorption nucleation
slow broadening by coalescence aided by turbulence
vapor deposition
riming
continued coalescence
frozen drops heterogeneous freezing (immersion /contact)
Snow Crystals
Secondary Ice Particles
riming
aggregation
clumping
continued coalescence
secondary ice particles
Snow Flakes
partial melting
shedding
Bright Band
freezing
graupels
partial melting
rimed crystals
Bright Band
melting
freezing
shedding
DRIZZLE WARM RAIN
SLEET
GRAUPELS
HAIL
SNOW GRAINS
RAIN
SNOW
GRAUPELS SNOW PELLETS HAIL
RAIN
SLEET
WARM RAIN

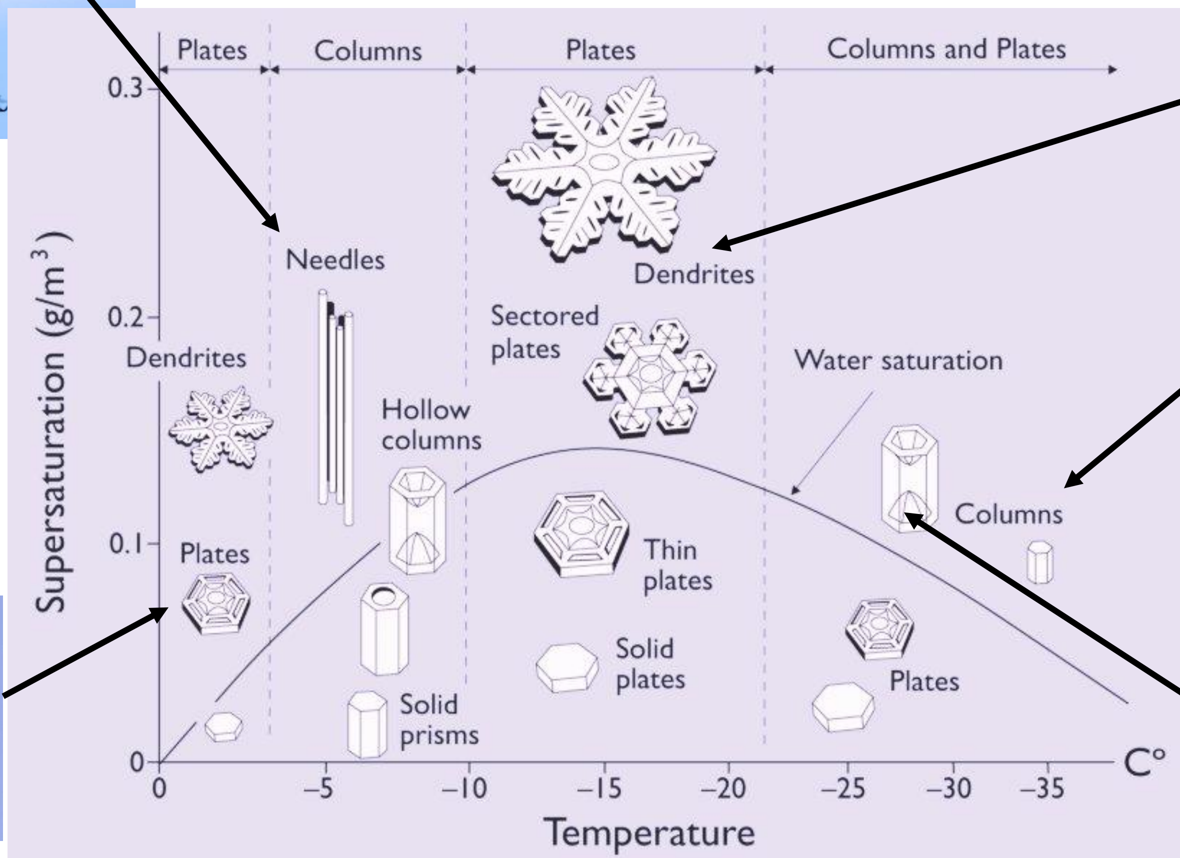
Diffusional growth of ice crystals

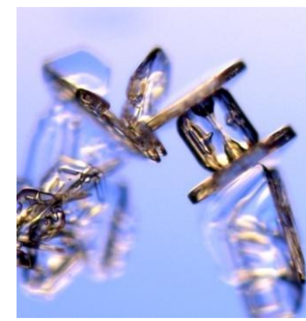
Ice Habits

Ice habits can be complex, depend on temperature: influences fall speeds and radiative properties





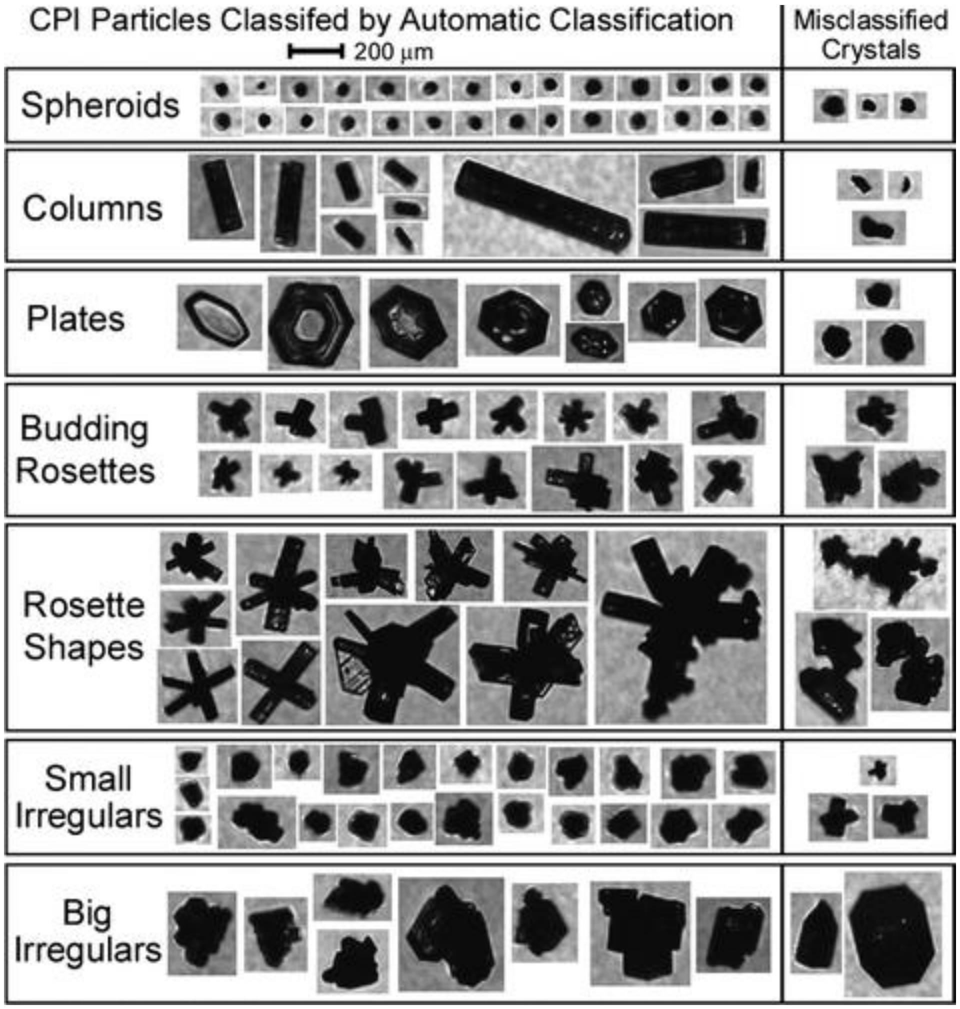


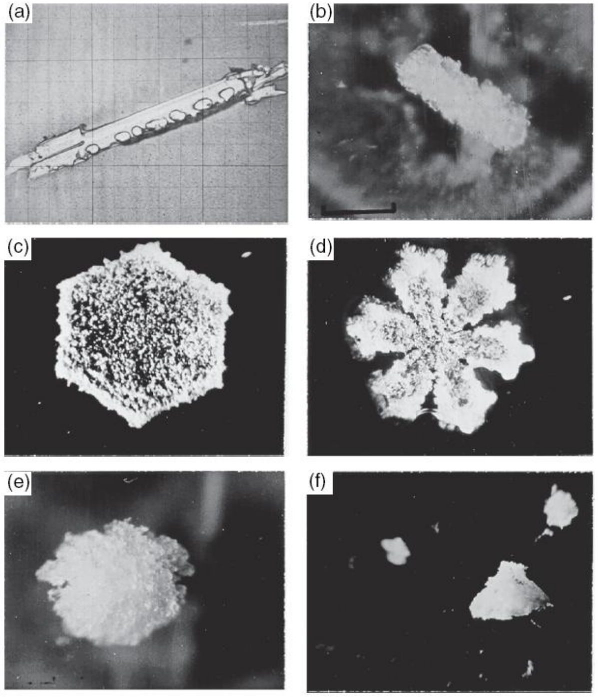


http://www.its.caltech.edu/~atomic/snowcrystals/

“No two snowflakes are exactly the same”

Lawson et al. 2006





Microphysics schemes in WRF

- \- microphysics

  * Kessler

  * WRF Single Moment (WSM) 3, 5 and 6 class

  * Lin et al.

  * Eta Ferrier

  * Thompson

  * Goddard 6 class

  * Morrison 2-moment

  * WRF Double Moment (WDM) 5 and 6 class

  * Thompson scheme from old version

  * Milbrandt-Yau double moment

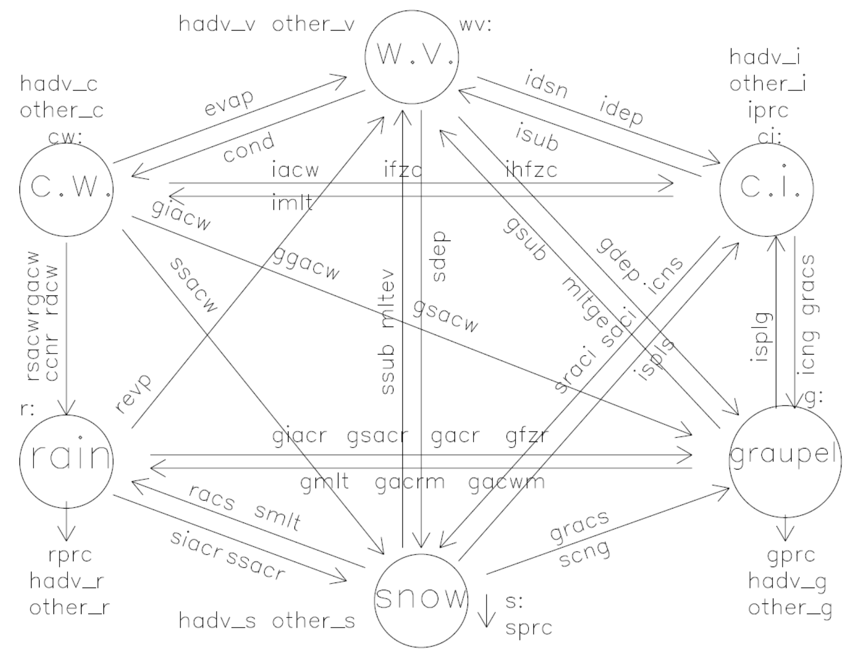
  * Stony-Brook University Lin scheme

A New Bulk Microphysical Parameterization

- Consider both shape and riming dependent ice properties
- More physically-based and simplified

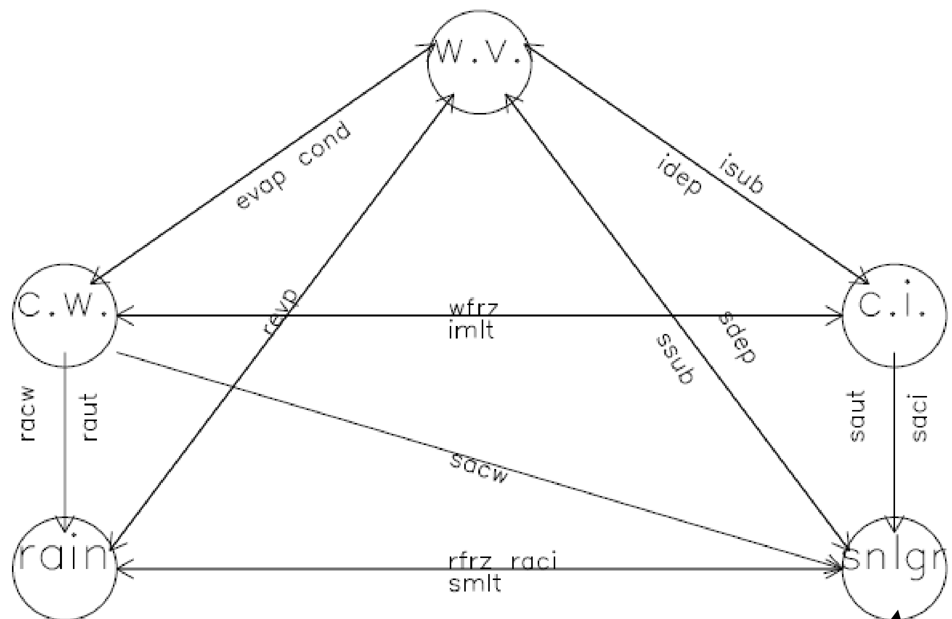
Saves 5-10% model simulation time

< 20 processes



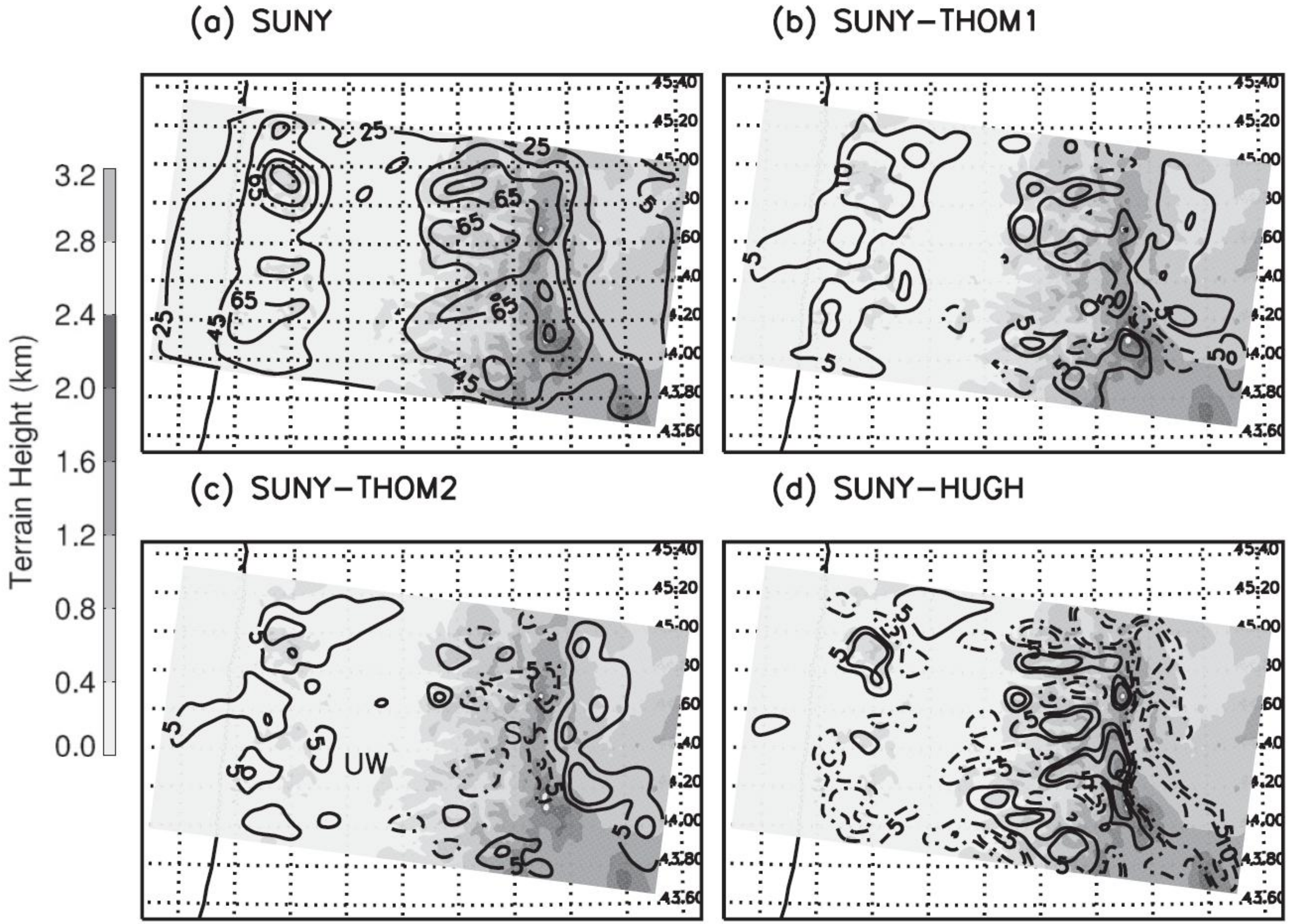
Thompson et al. 2004

> 40 processes



Precipitating ice (PI) covering the continuous spectrum from dry snow to graupel using Riming intensity (*Ri*)

An example of BMP on precipitation



Cloud and precipitation observations

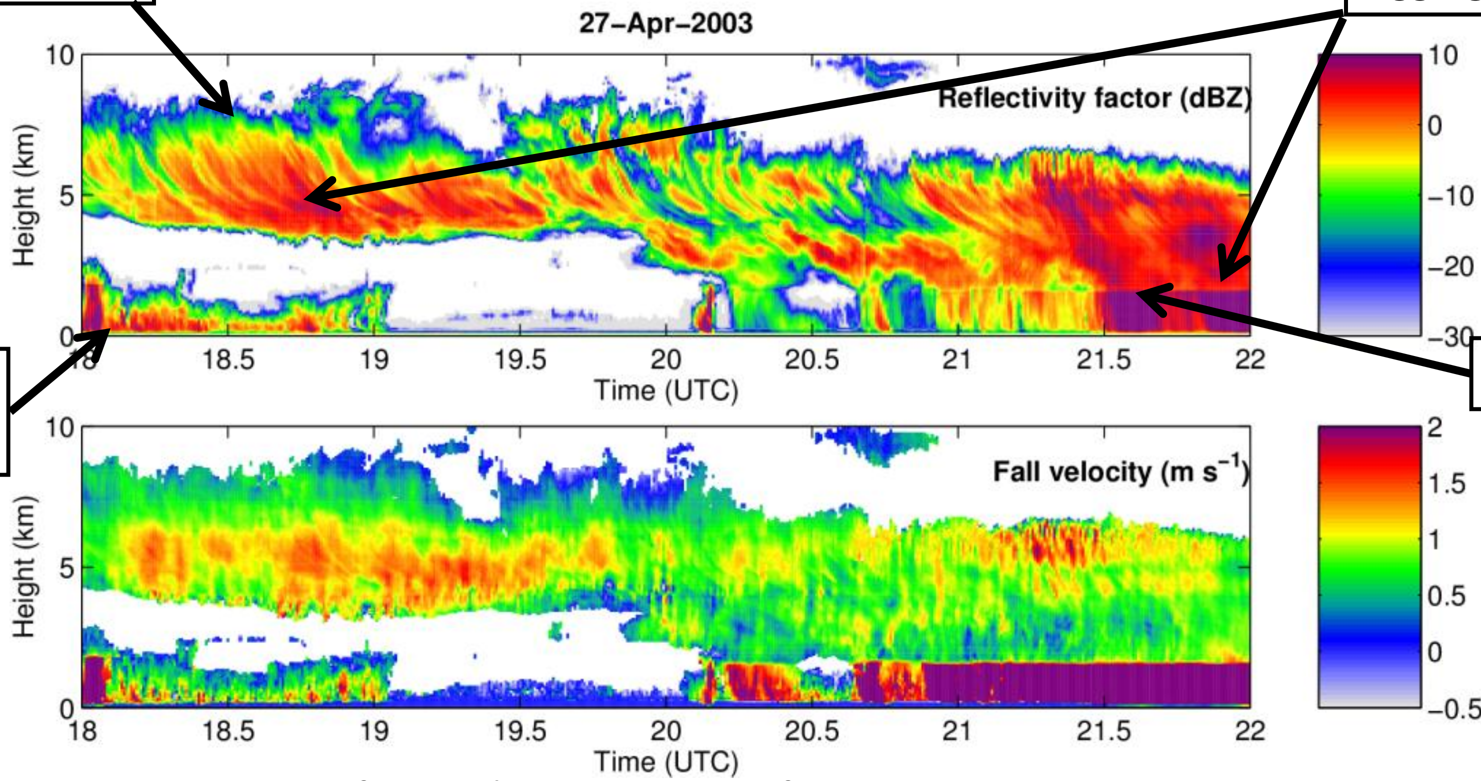
- Remote sensing
- In situ measurements

Microphysics at the Cloud Scale

Typical time-height cross section of a front from the vertically pointing 94GHz radar at Chilbolton, UK

Ice Nucleation and diffusion growth

Aggregation

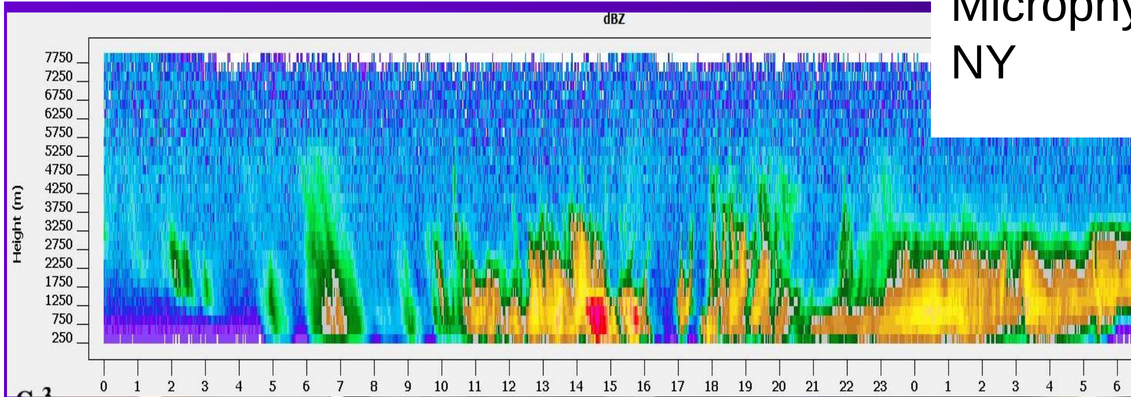


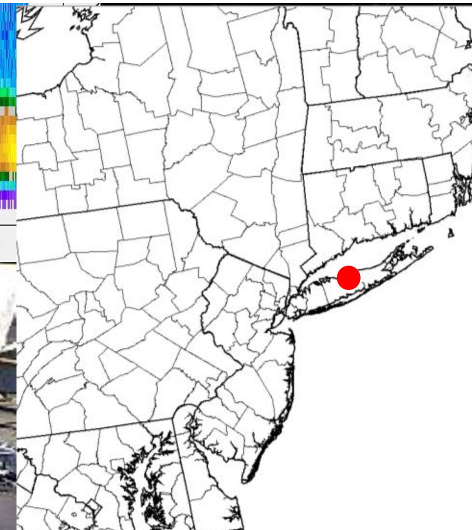
Melting

Warm phase

Image from Robin Hogan. Data from RCRU RAL.

Microphysical Observations at Stony Brook, NY

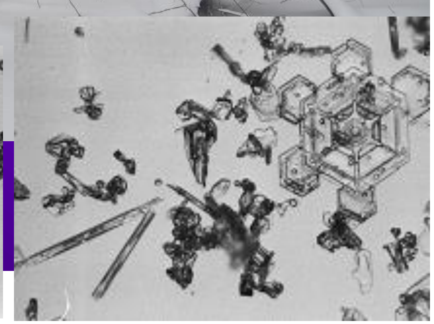


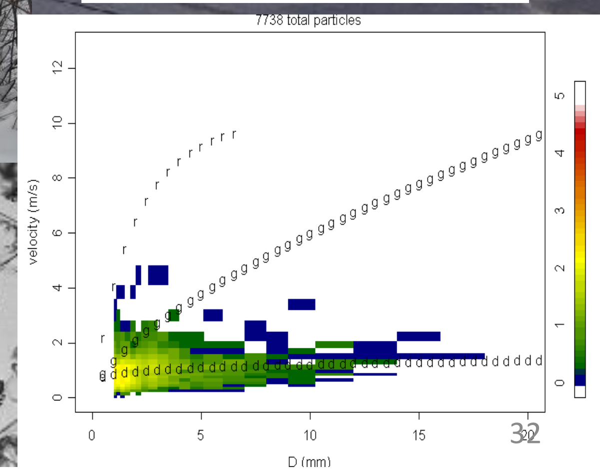


MRR vertically-pointing radar

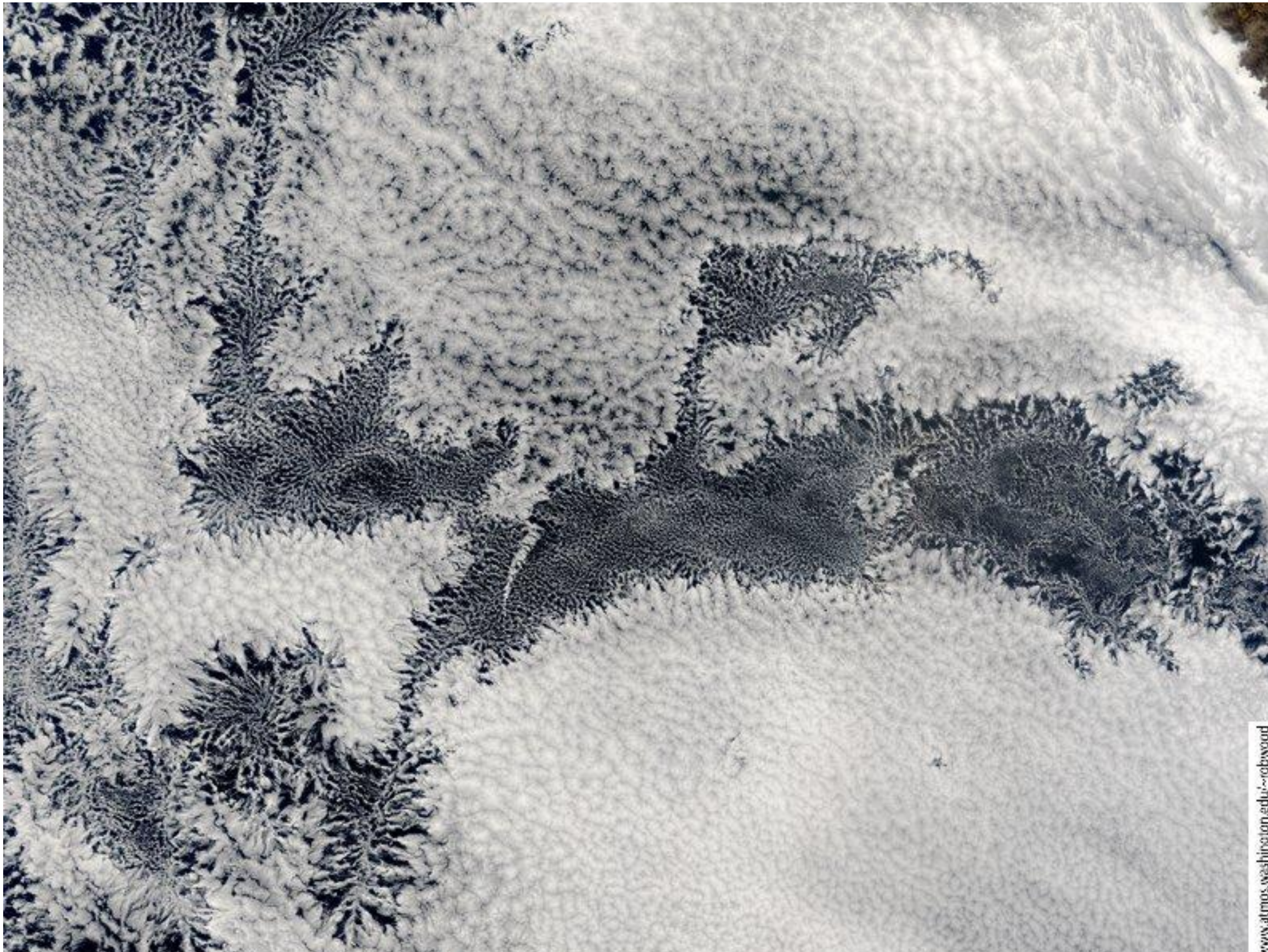
precip gauge

snow/rain particle imager

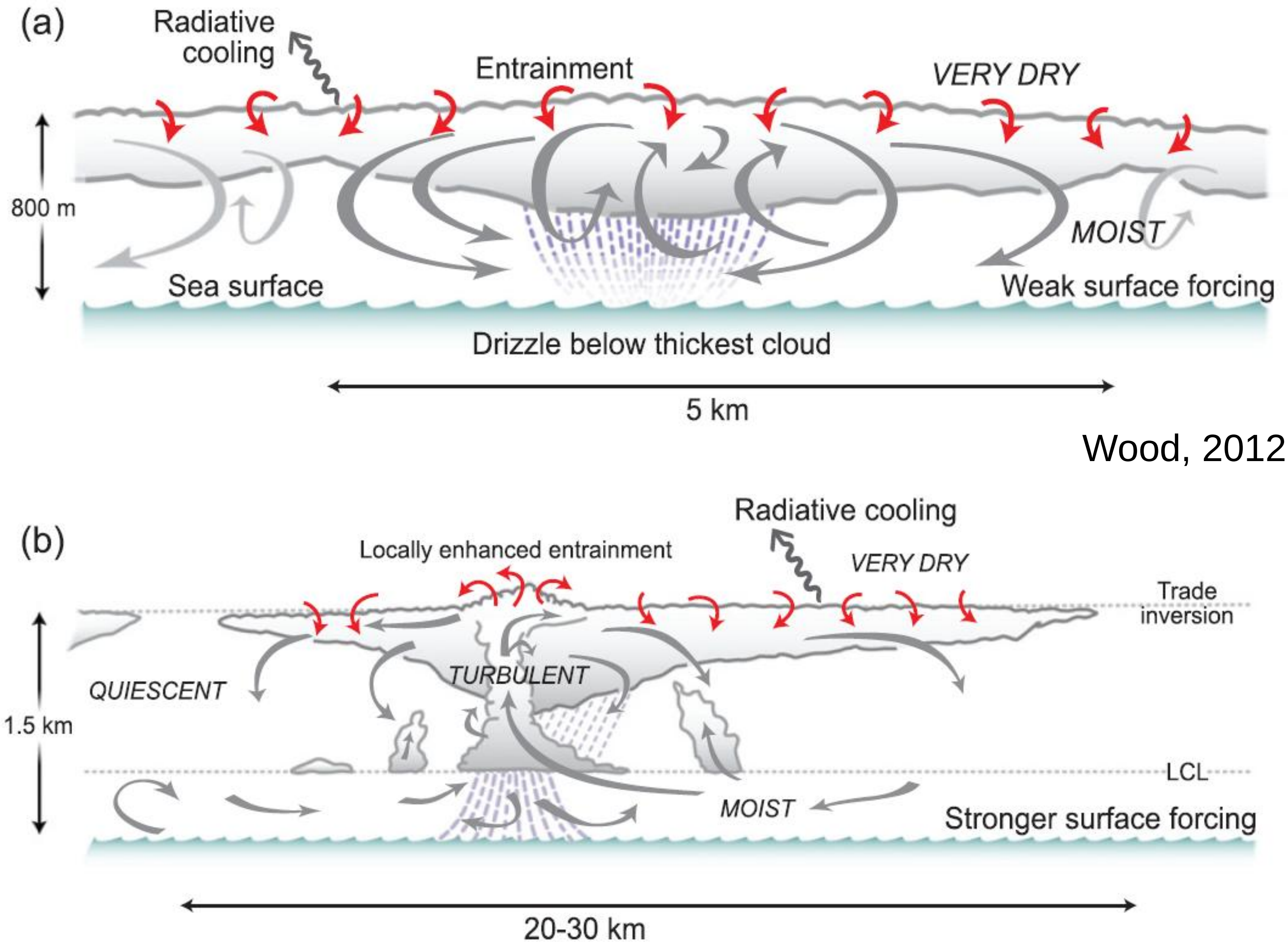




Complex structures

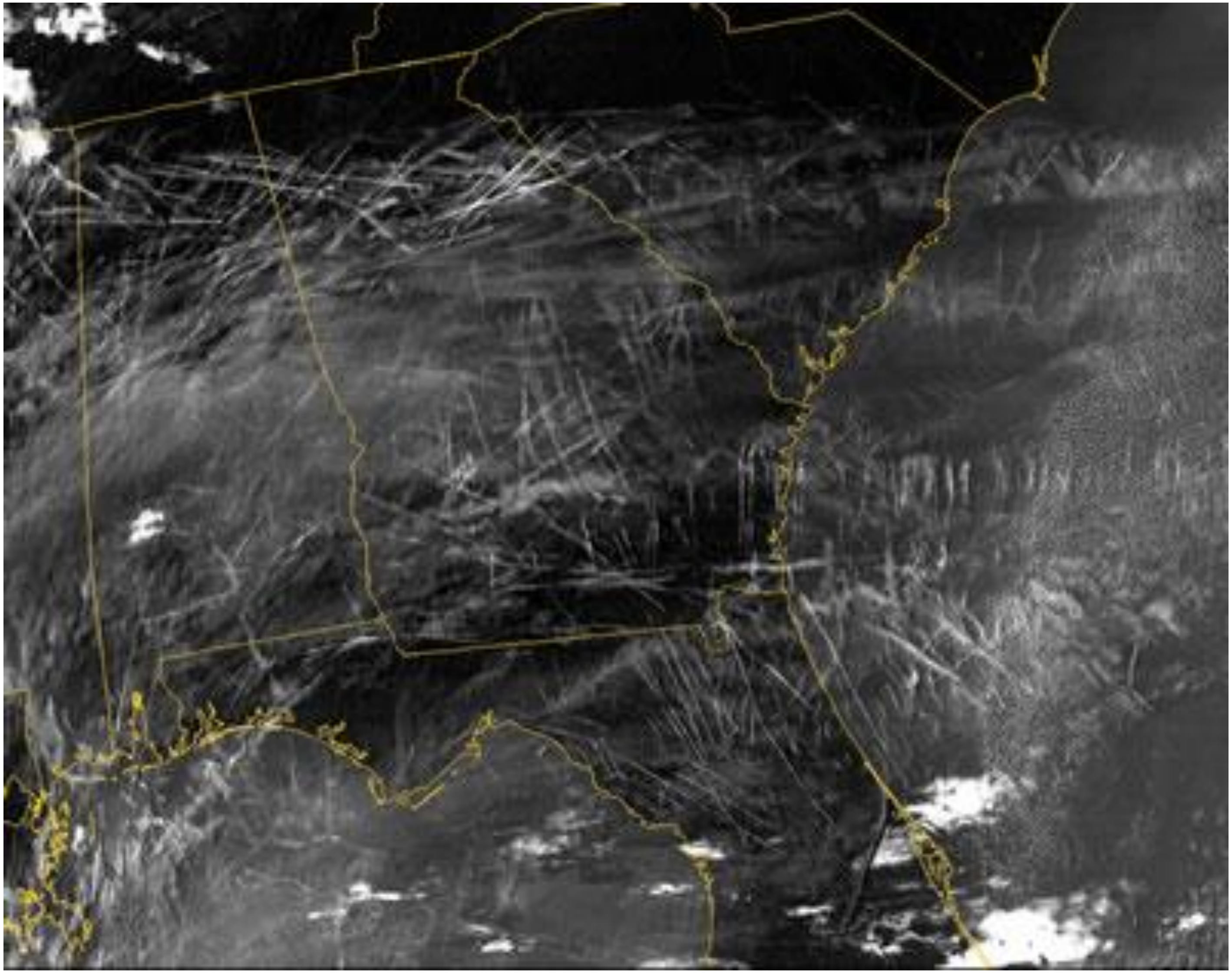


Structure of marine stratocumulus

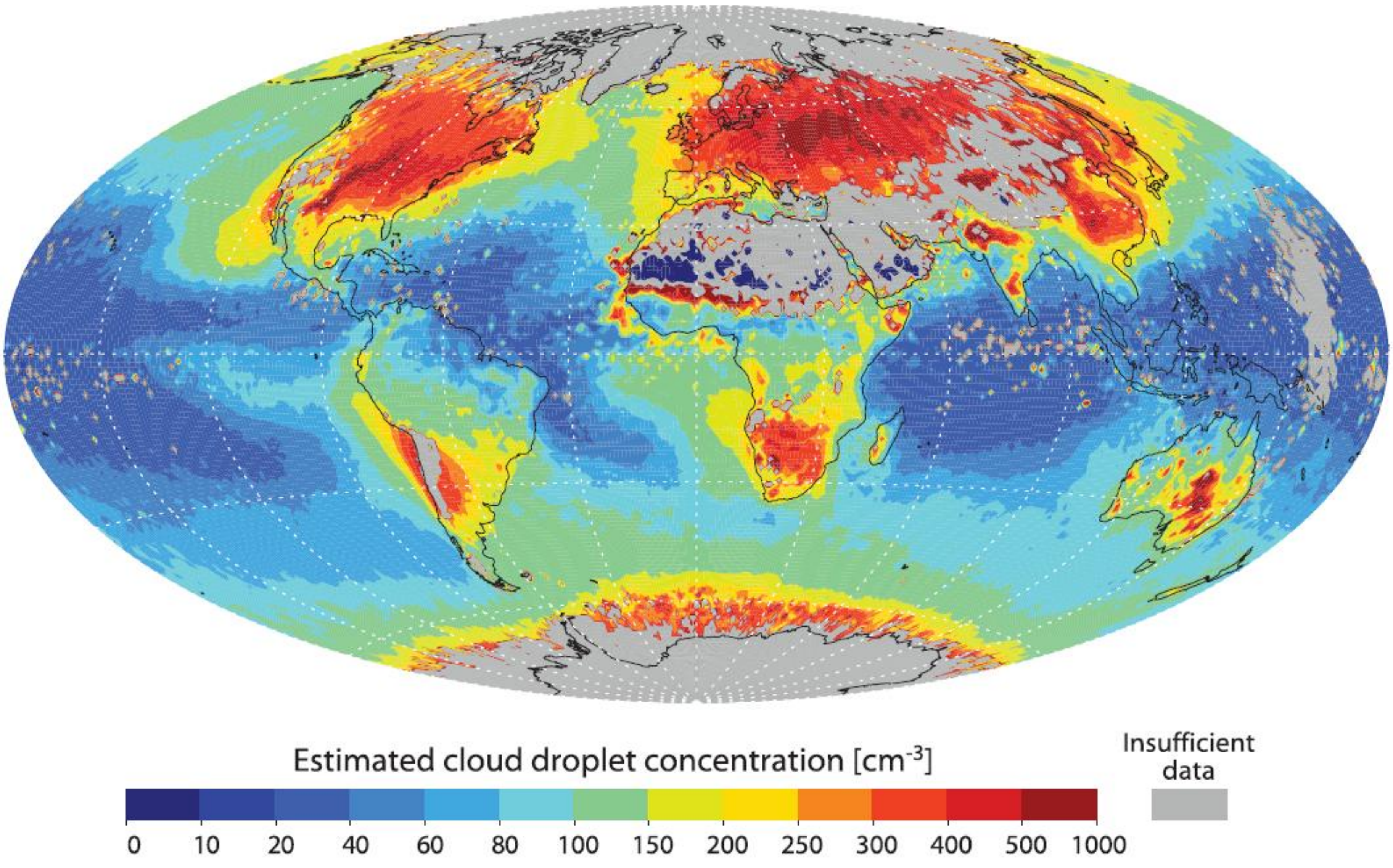


Wood, 2012

Aircraft contrails



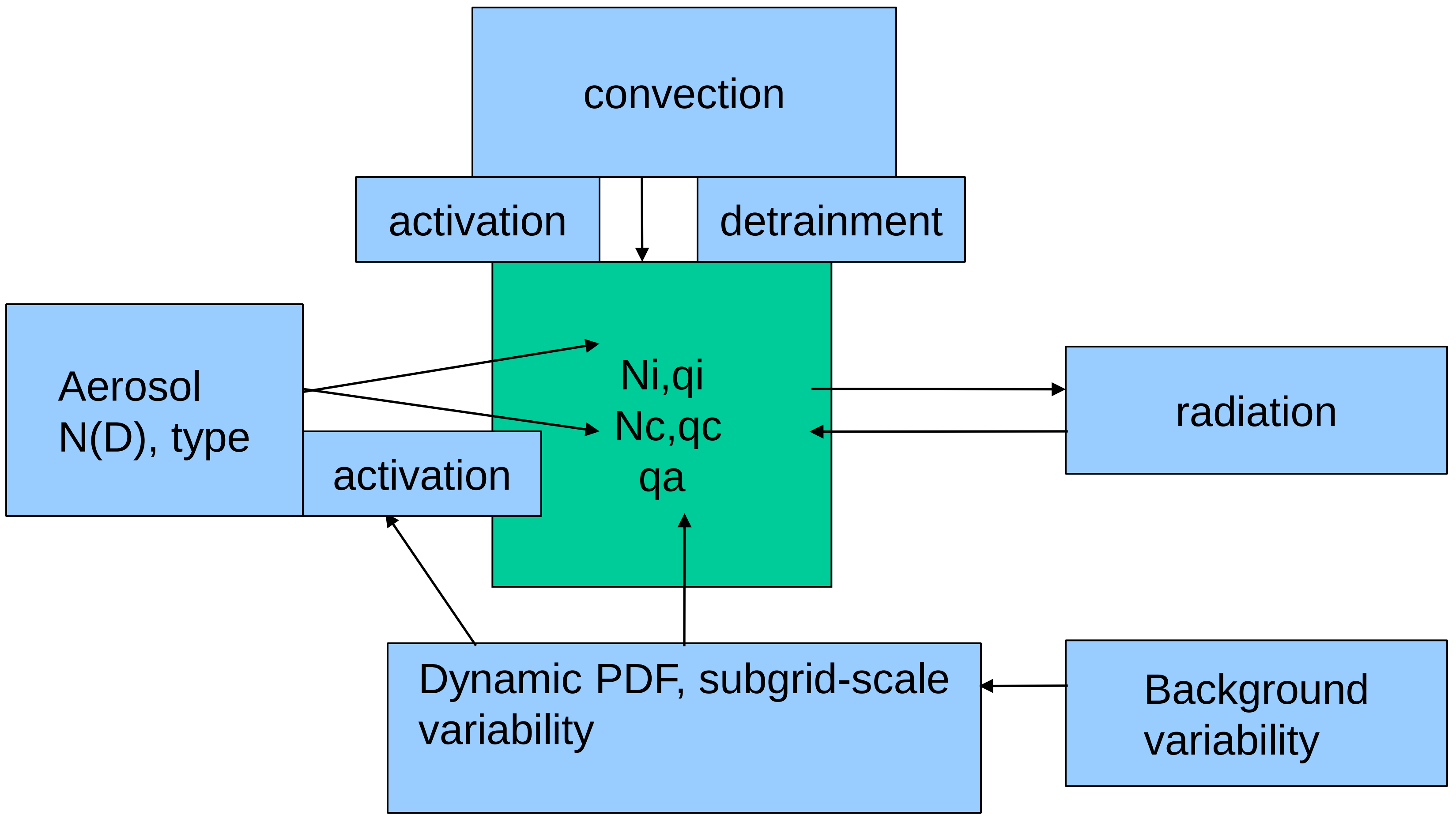
How aerosol impact cloud?



A deadlock (Randall et al. 2003)

We should be asking ourselves: **Is it really possible to parameterize all of this complexity with quantitative accuracy?** Collectively, we, the authors of this paper, have been working on the problem for almost a century. **Are we having fun yet? Definitely yes.** Cloud parameterization is a beautiful, important, infinitely challenging problem, and we continue to be fascinated and excited by it. We and the other members of our research community have made important progress, of which we should be proud, and we have no doubt that progress will continue. **Nevertheless, a sober assessment suggests that with current approaches the cloud parameterization problem will not be "solved" in any of our lifetimes.**

A dream unified cloud scheme



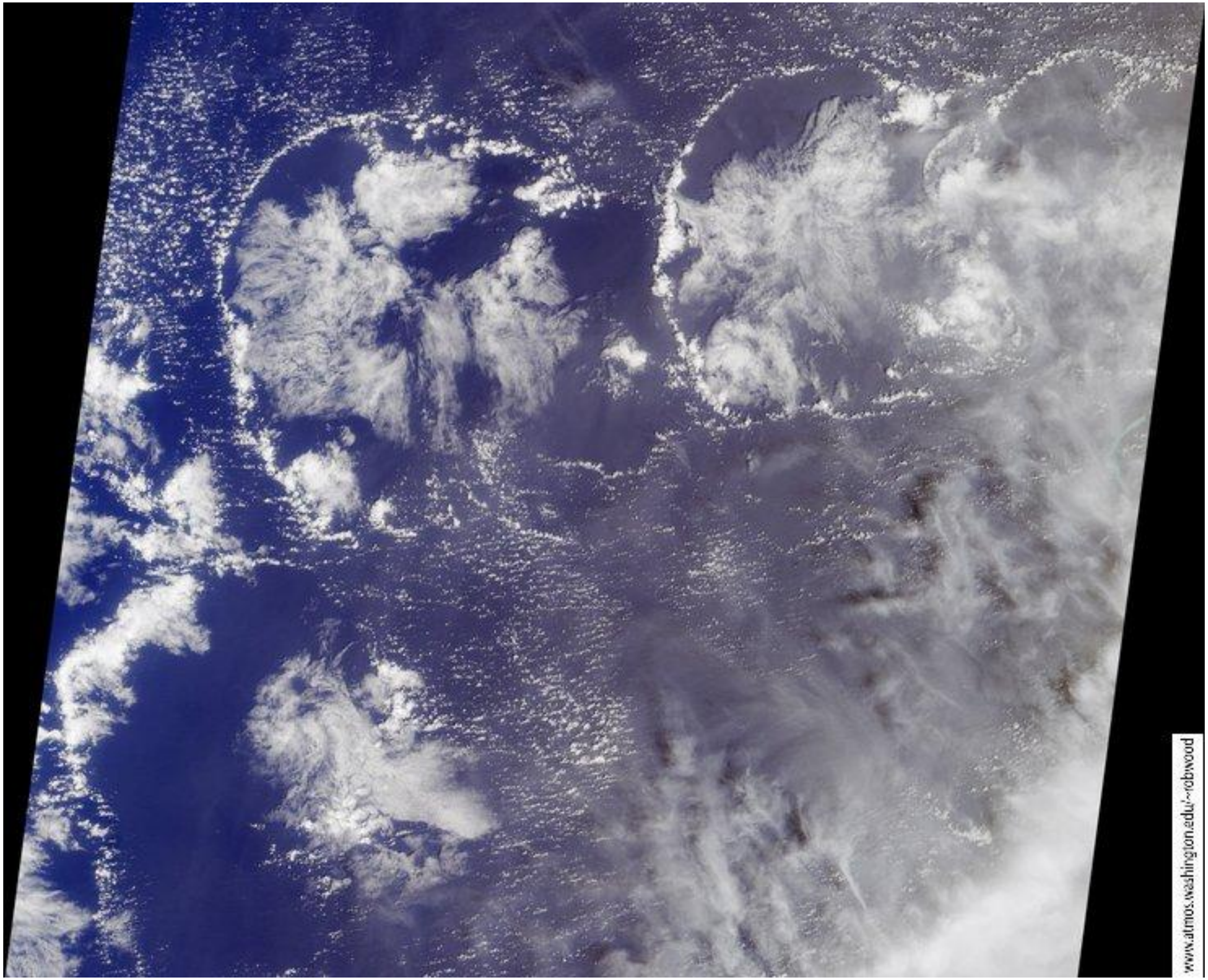
A long way to go and need comprehensive test and evaluation !

Further reading

- Arakawa 2004: The cumulus parameterization problem: past, present, and future.
- Randall et al., 2003: Breaking the cloud parameterization deadlock. BAMS.
- Lopez, Philippe, 2007: *Cloud* and Precipitation *Parameterizations* in Modeling and Variational Data Assimilation: A *Review*. J. Atmos. Sci., 64, 3766–3784.
- Wood, R. 2012: stratocumulus clouds. A review. Mon. Wea. Rev.

Thanks!


www.atmos.washington.edu/~robwood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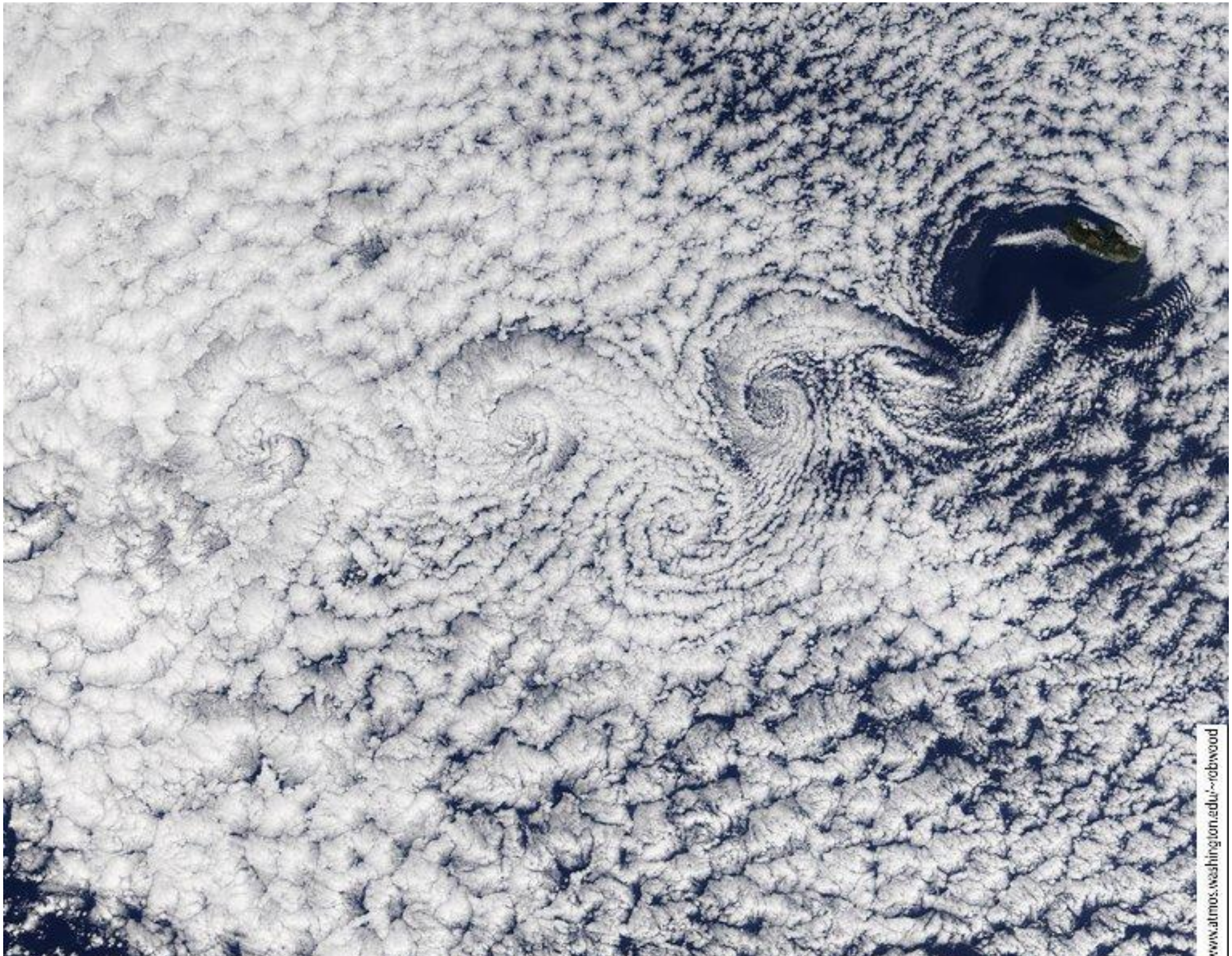
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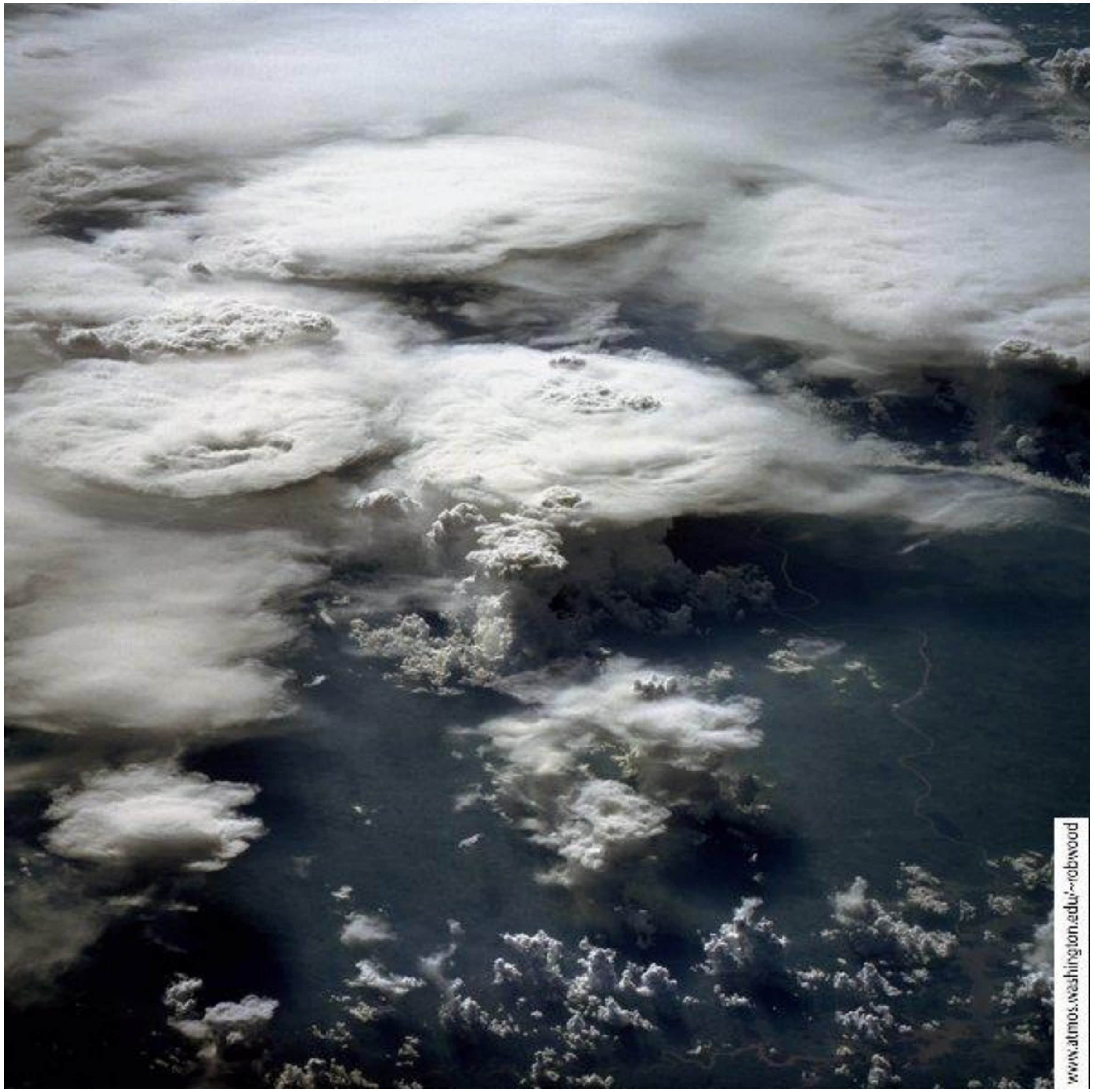
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