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The use of detailed cloud models in cloud seeding research - A review

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Outline

- Background – what are we doing in cloud seeding ?
- Some perspectives on the relationship between cloud models and weather modification.
- Examples

Cloud Seeding

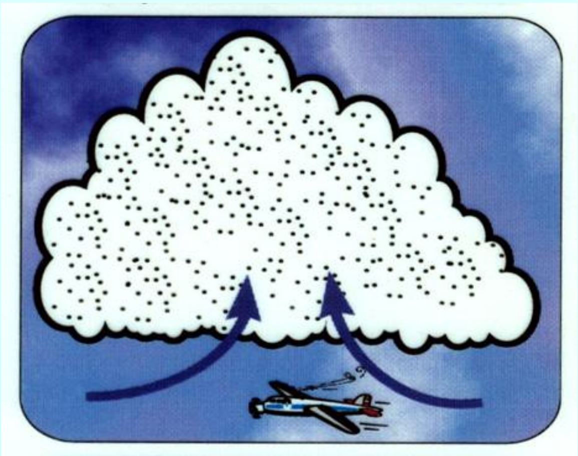
Hygroscopic seeding

↓

To increase the concentrations of giant CCN and enhance the production of raindrops

↓

Sodium Chloride



Glaciogenic Seeding

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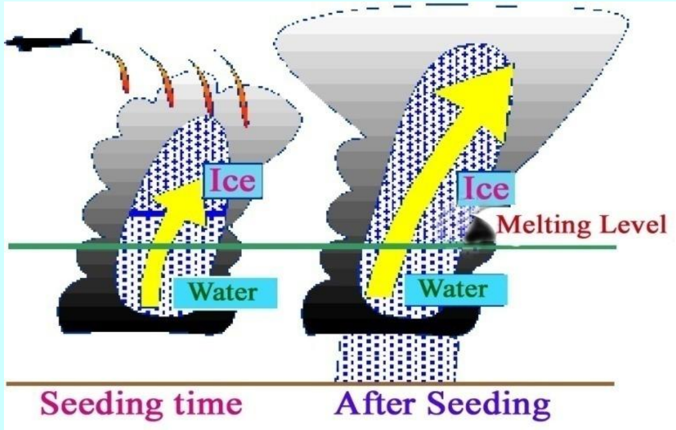
To increase population of ice crystals

↓

Seeding with Silver Iodide, dry ice



WMO criteria for successful rain enhancement experiments (*List, 2004*)

- The increase of rain has to be measured at <u>the ground</u>
- Evaluation has to be based on randomized experiment
- There has to be a physical explanation for the increase (or the decrease) in rainfall.
- Success has to be repeated in other areas of the world (transferability).

What can be done with models?

- Concept development
- Test seedability of clouds:
  - Type of clouds
  - Seeding type
  - Seeding material
  - Seeding levels,
  - Location of seeding
  - Time relative to the evolution of the cloud
  - Duration of seeding
- Experimental design
- Operational decisions
- Project evaluation
- Understanding of seeding effect

Major achievements in cloud seeding research from models

- **"Dynamic" seeding effect – Latent heat release from drops freezing and glaciation cause cloud invigoration.**
- **"Static" seeding has dynamic impact. Models show the complex interaction between cloud scale vs. mesoscale when seeding is included.**
- **The importance of GCCN in hygroscopic seeding.**
- **The importance of "seeding window" on cloud seeding efficiency. Determination of "seeding window" helps to decide which is seeding concept is recommended:**
    - Broad-scale seeding - Seeding of Ice Nuclei below cloud base along a predetermined line. Often ground generators are used exclusively or in addition to airborne dispersal using predetermined tracks.
    - Target seeding - Seeding individual clouds based on their development stage. Cannons, rockets or airplanes are often used.
- **Seeding may effect only small area of the cloud.**
- **Overseeding (too many seeding agents) may decrease precipitation.**
- **Ice nucleation parameterization has important effect.**

The effect of aerosol loading

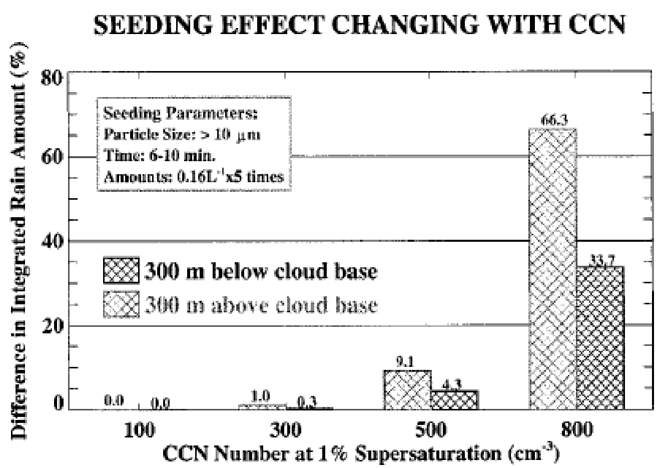
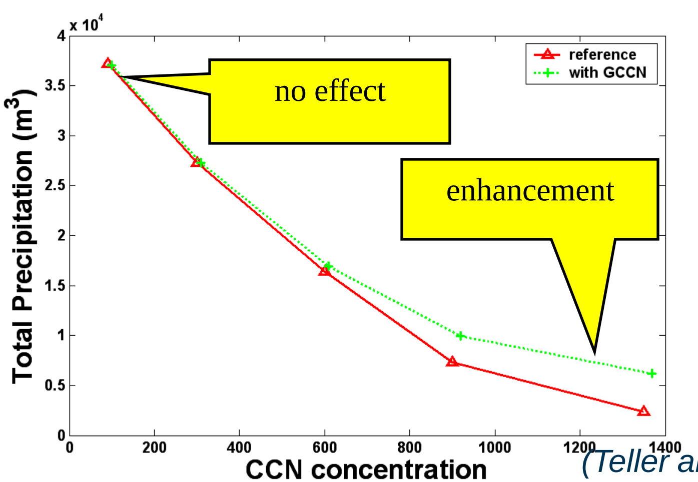


FIG. 9. Differences in integrated rain amount between the seeded and unseeded cases for clouds with different natural CCN.

(Yin et al., 2000)



(Teller and Levin, 2006)

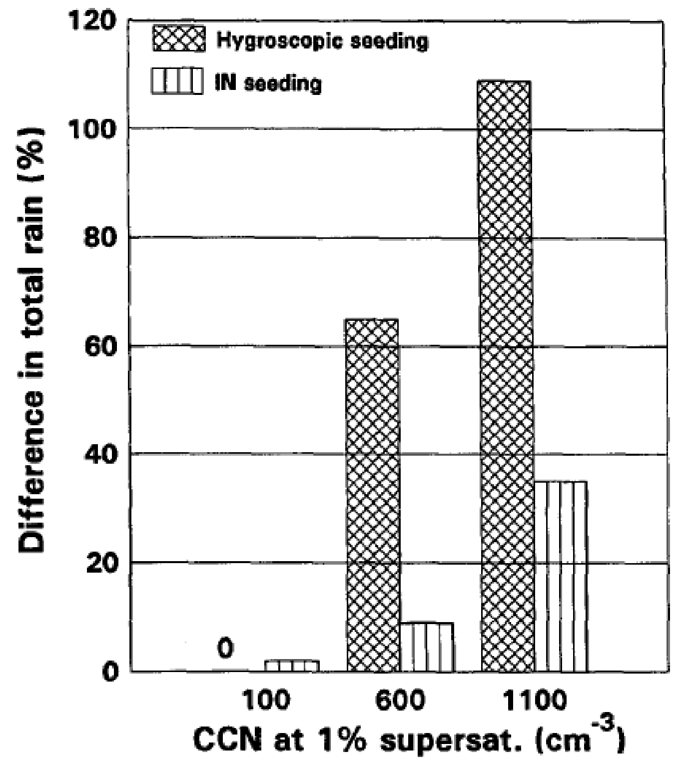
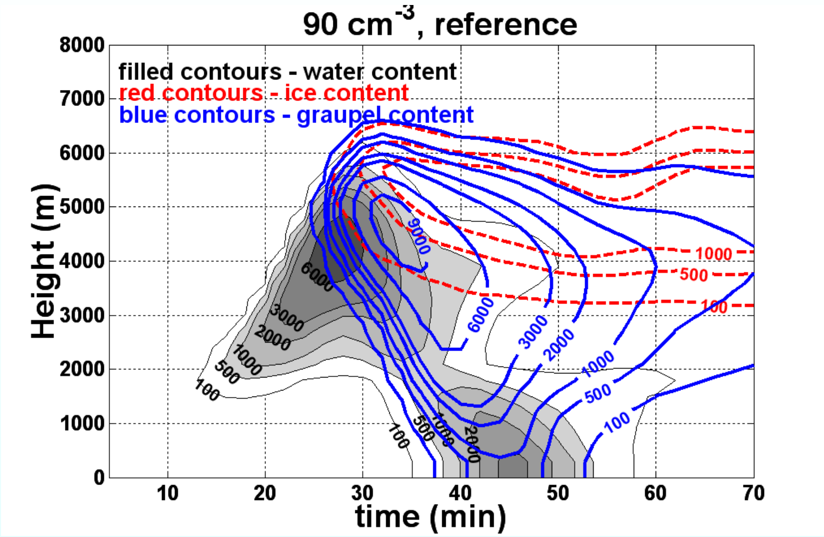


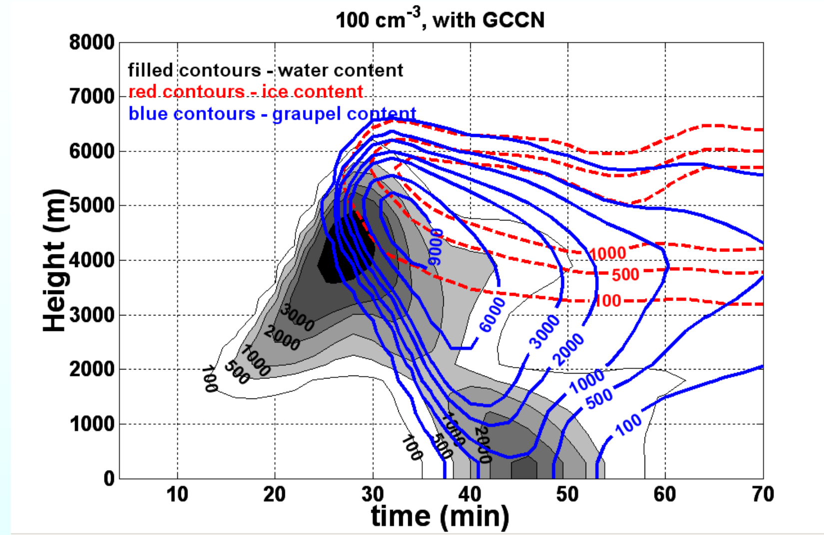
FIG. 7. The difference between seeded and unseeded clouds (as a percentage and in cubic meters) of the total rain for seeding the different reference clouds with hygroscopic particles. For comparison, the best results obtained for IN seeding are also shown. The seeding was conducted at cloud base once a minute during 5 min at the time of maximum convection. The total amount of seeding material was 450 kg.

(Reisin et al., 1996)

GCCN effect on total precipitation

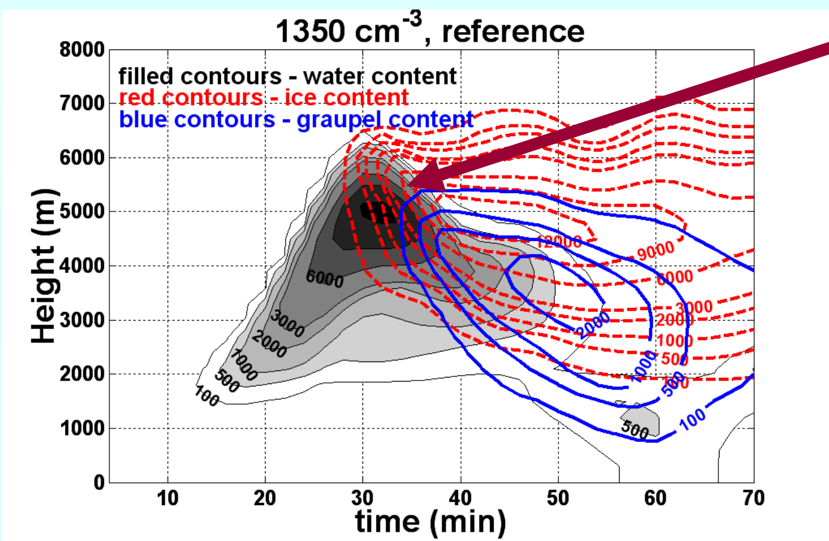
Clean cloud

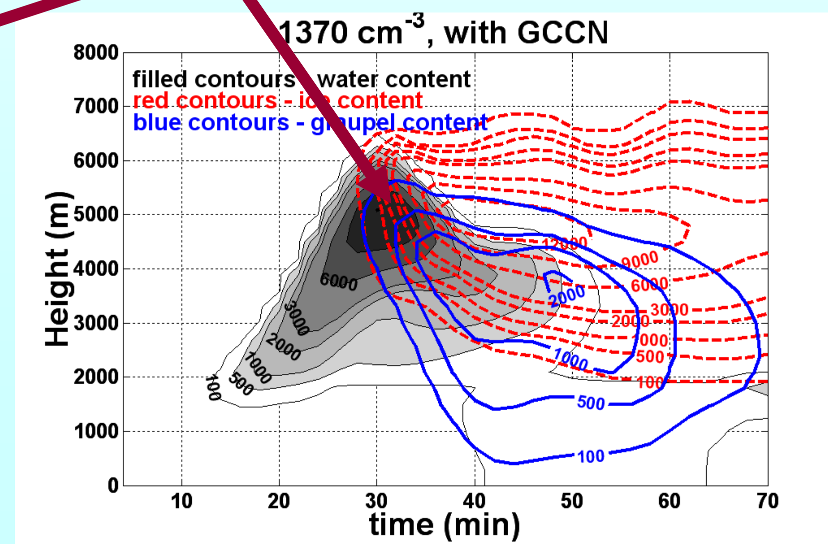




Polluted cloud

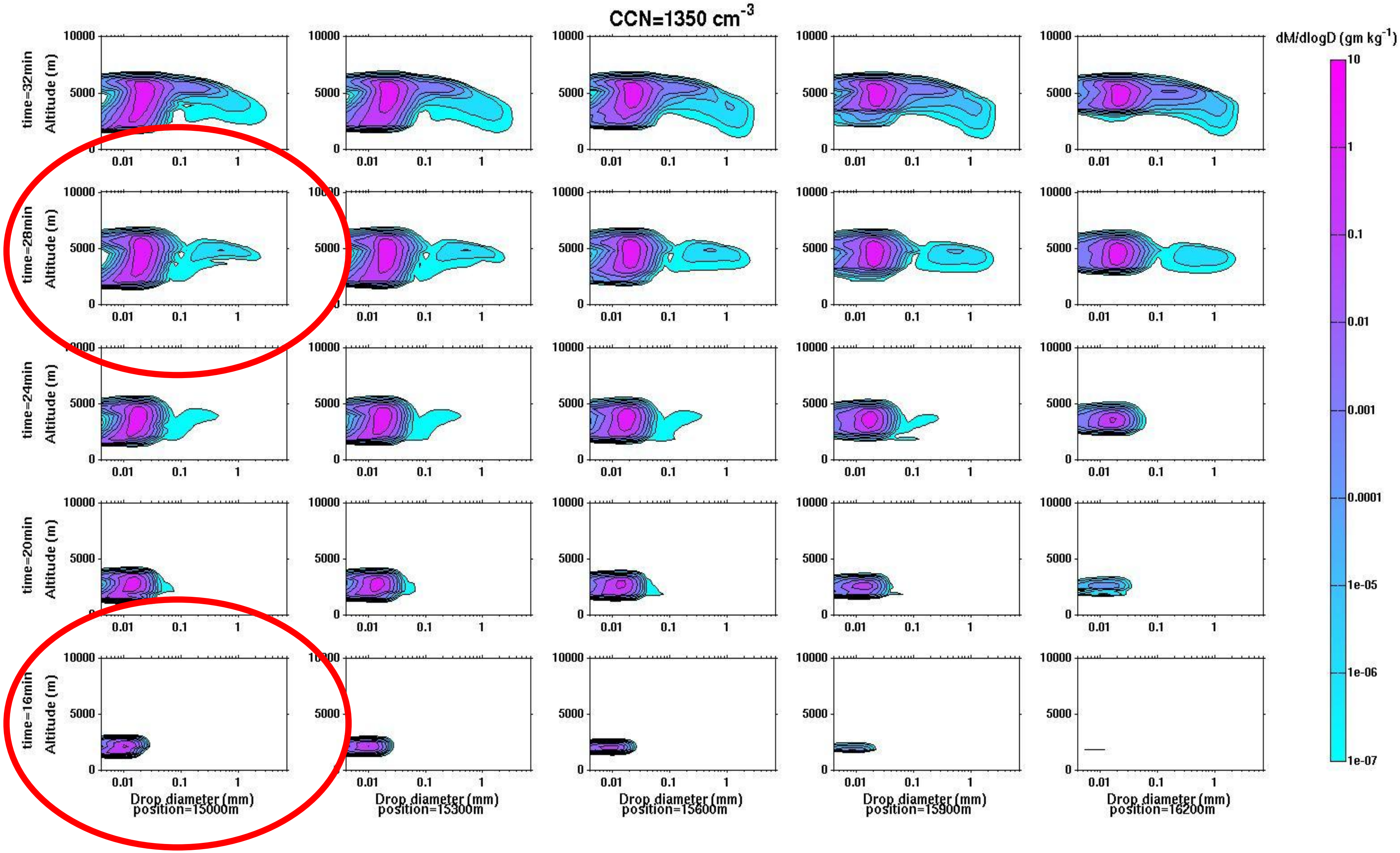
Graupel production





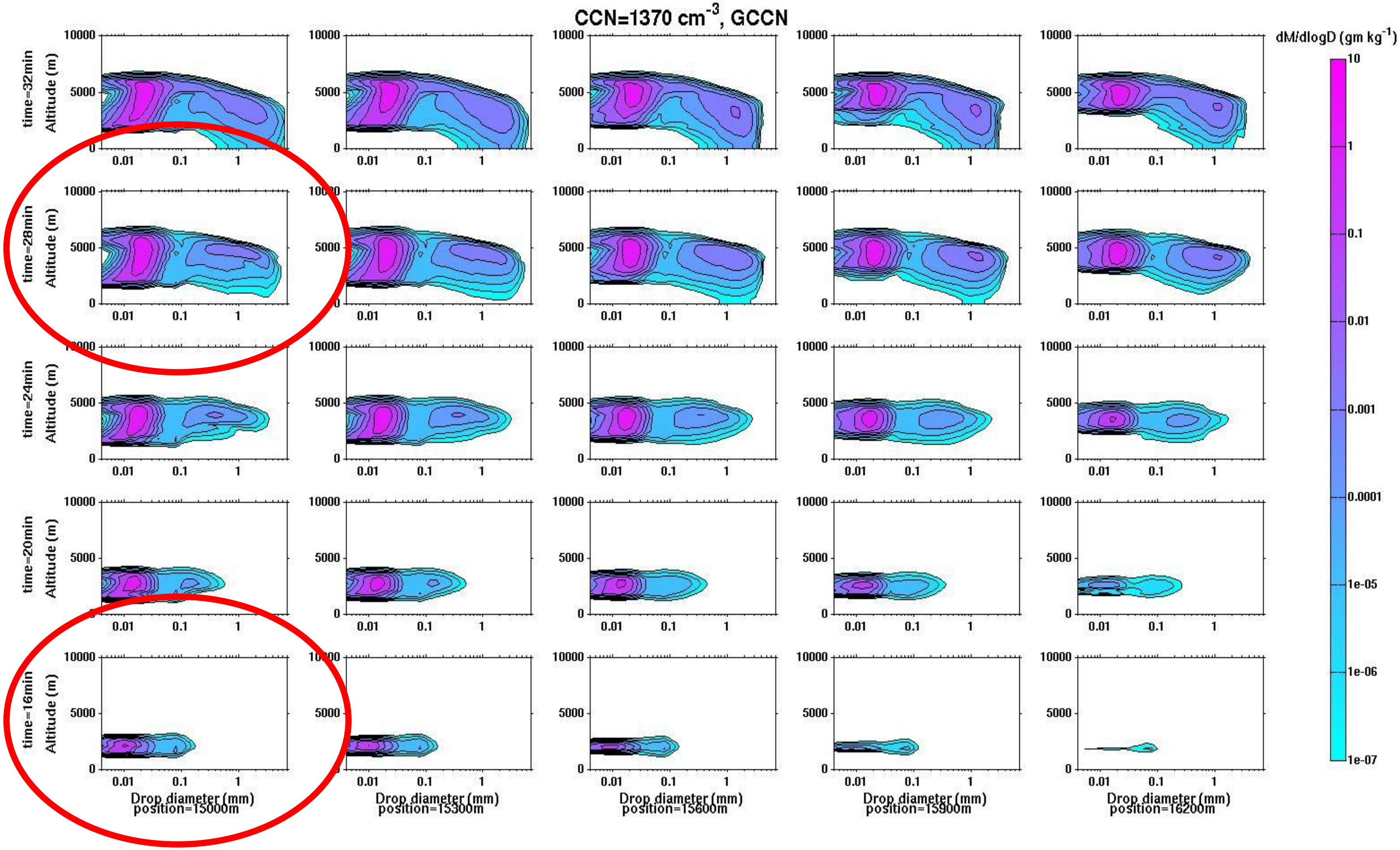
Bin-microphysics properties – Droplet Mass Distribution

Polluted case



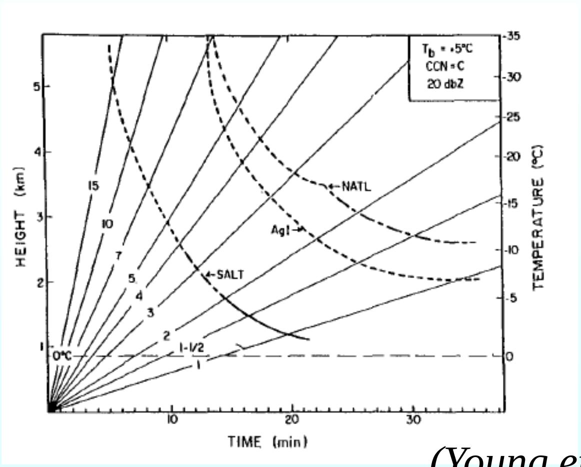
Bin-microphysics properties – Droplet Mass Distribution

Polluted case – with GCCN



Time to initiate precipitation

Time to initiate precipitation for different cloud and different seeding types



(Young et al., 1996)

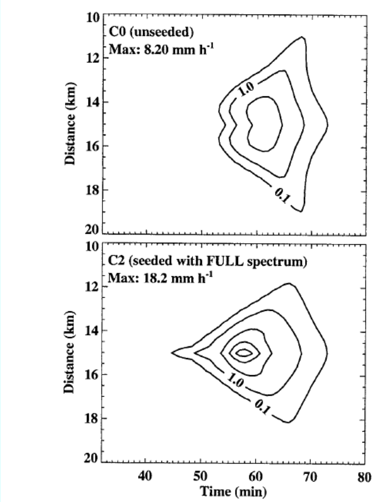
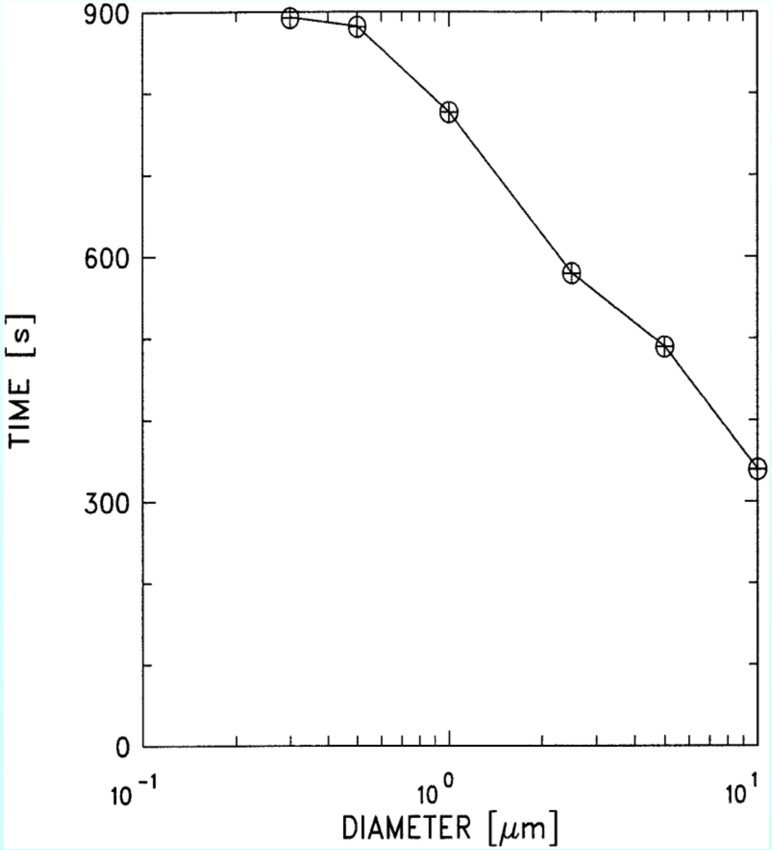


FIG. 6. Rainfall rate on the ground as a function of time in the unseeded case (top) and seeded case (C2; bottom). The contours are 0.1, 1, 5, 10, 15 mm h^{-1}.

(Yin et al., 2000)

Sensitivity to size of seeding material

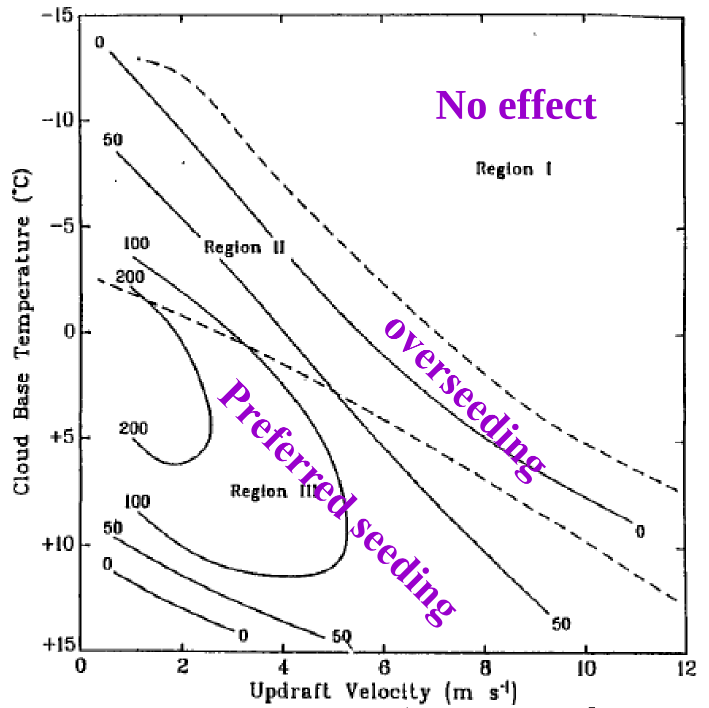
Time to convert 50% of condensation to precipitation



(Cooper et al., 1997)

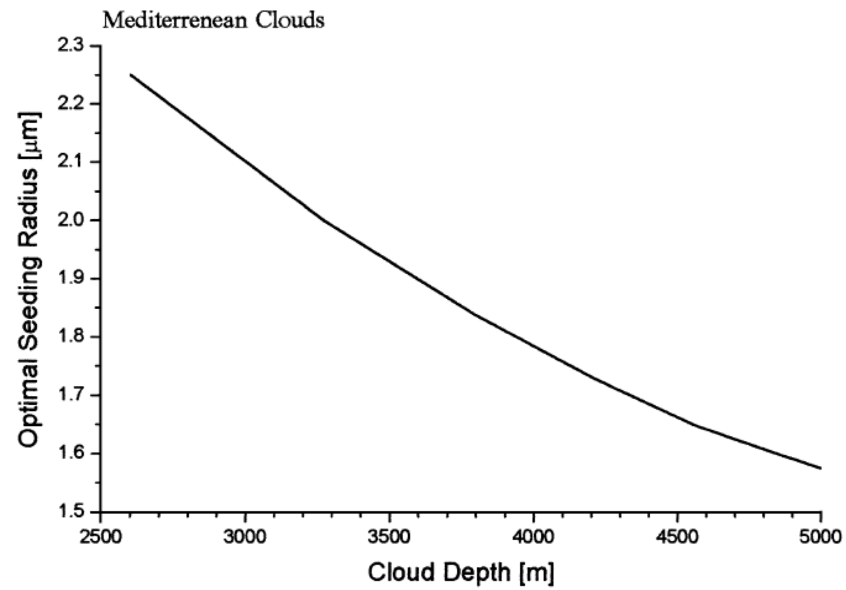
The size of the cloud

AgI seeding

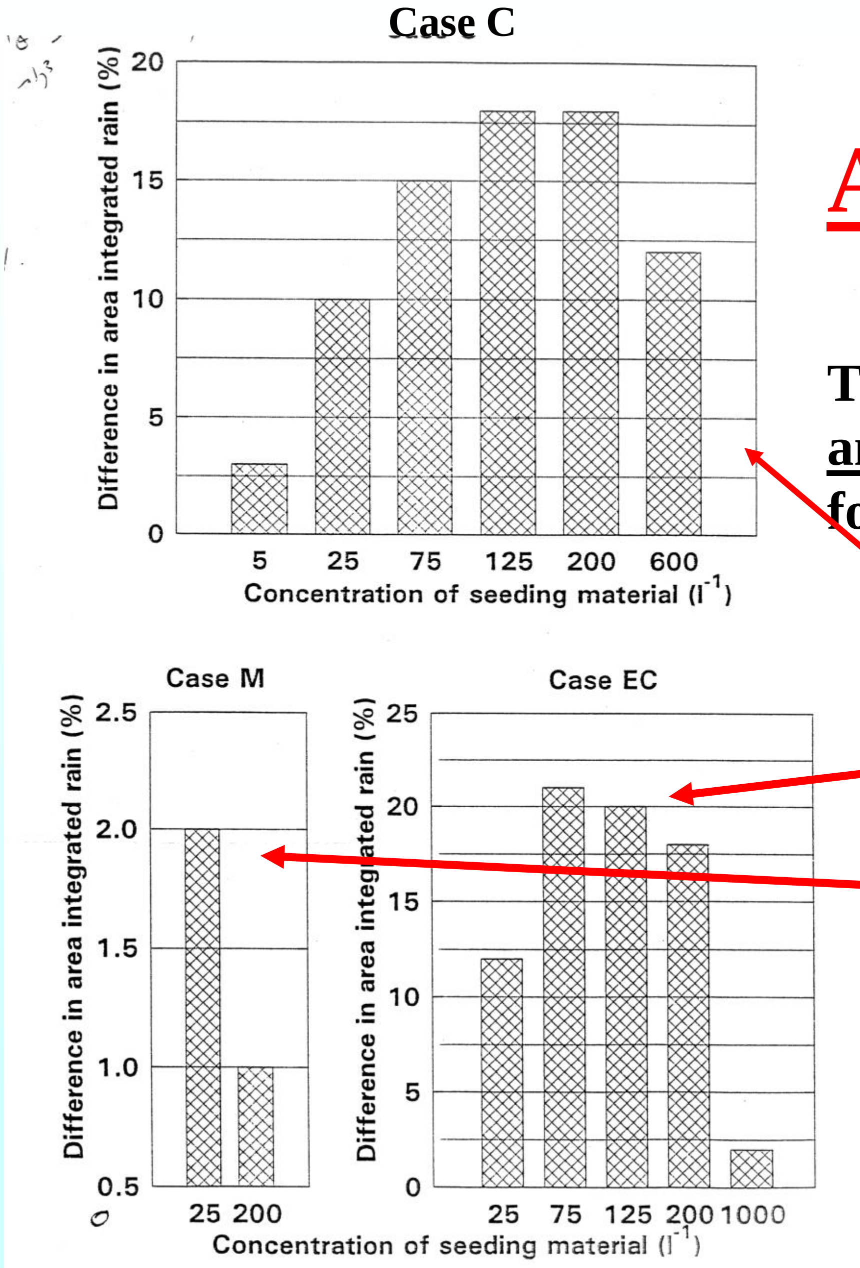


(Young et al., 1996)

Hygroscopic seeding



(Segal et al. 2004)



Amount of AgI seeding

The effects of different seeding amounts on rain production for different types of clouds:

C – Continental clouds (600/cm3)

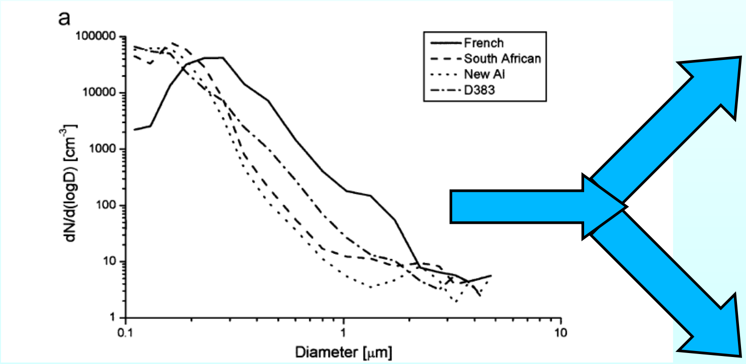
EC – Extreme continental (900/cm3)

M – Maritime cloud (200/cm3)

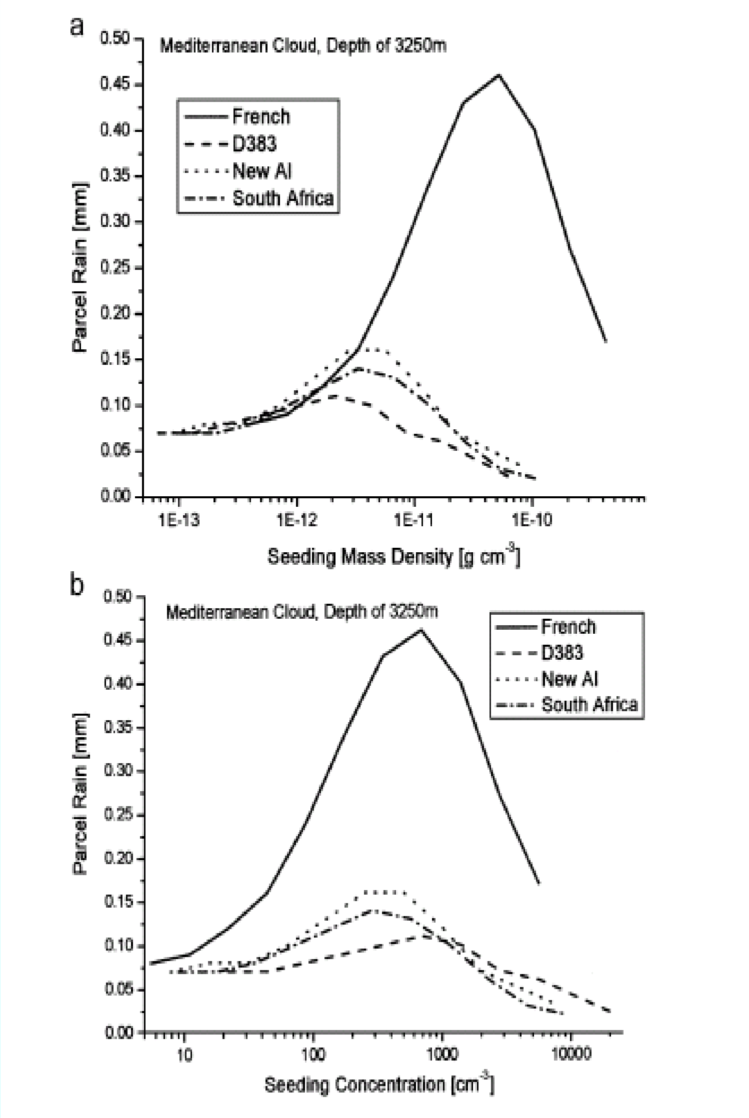
(Reisin et al., 1996)

Amount and size of hygroscopic seeding

Rain amount by hygroscopic seeding –
Effect of seeding material



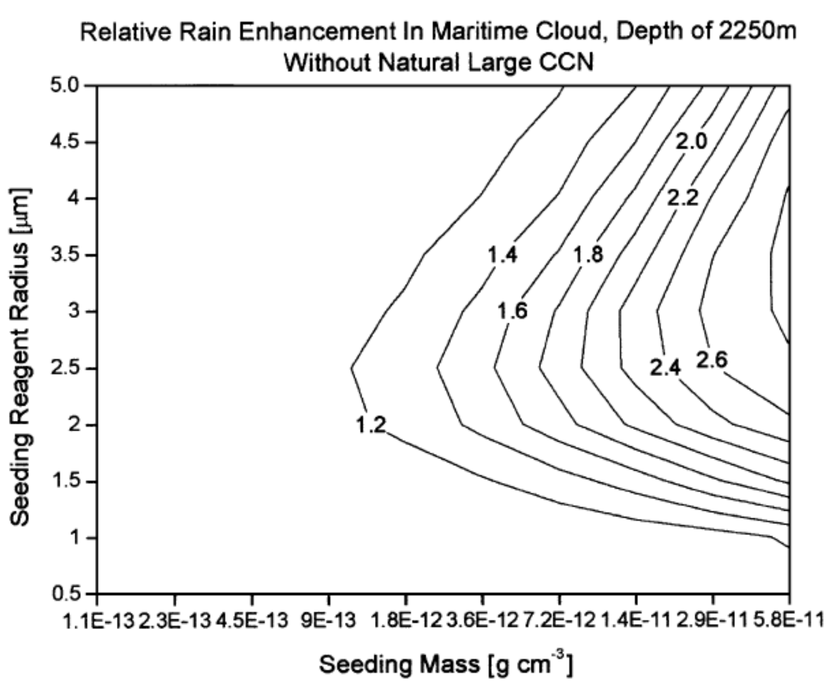
(Segal et al. 2004)



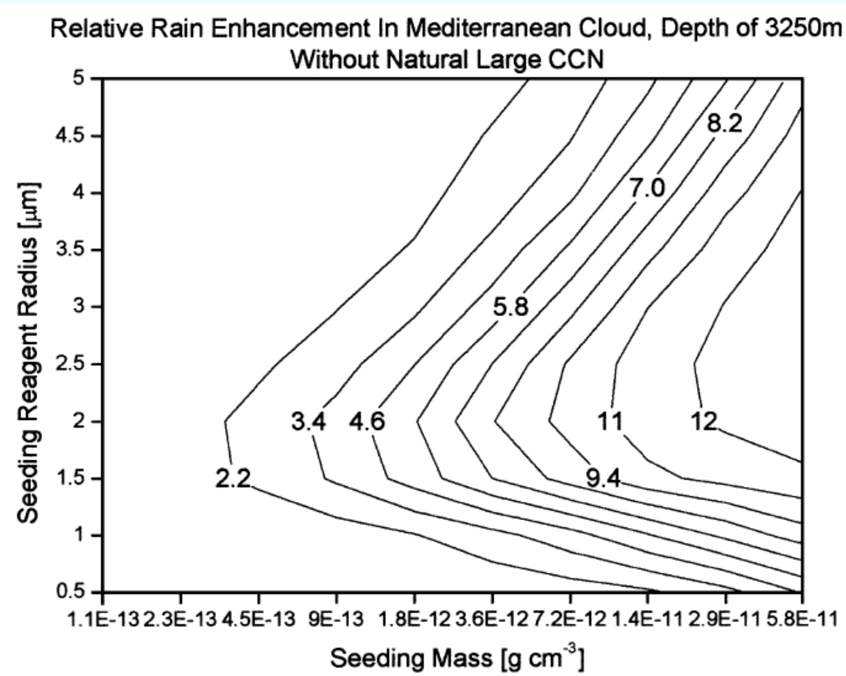
Amount and size of hygroscopic seeding (2)

Rain enhancement by hygroscopic seeding –
Effect of seeding mass, maritime and polluted conditions

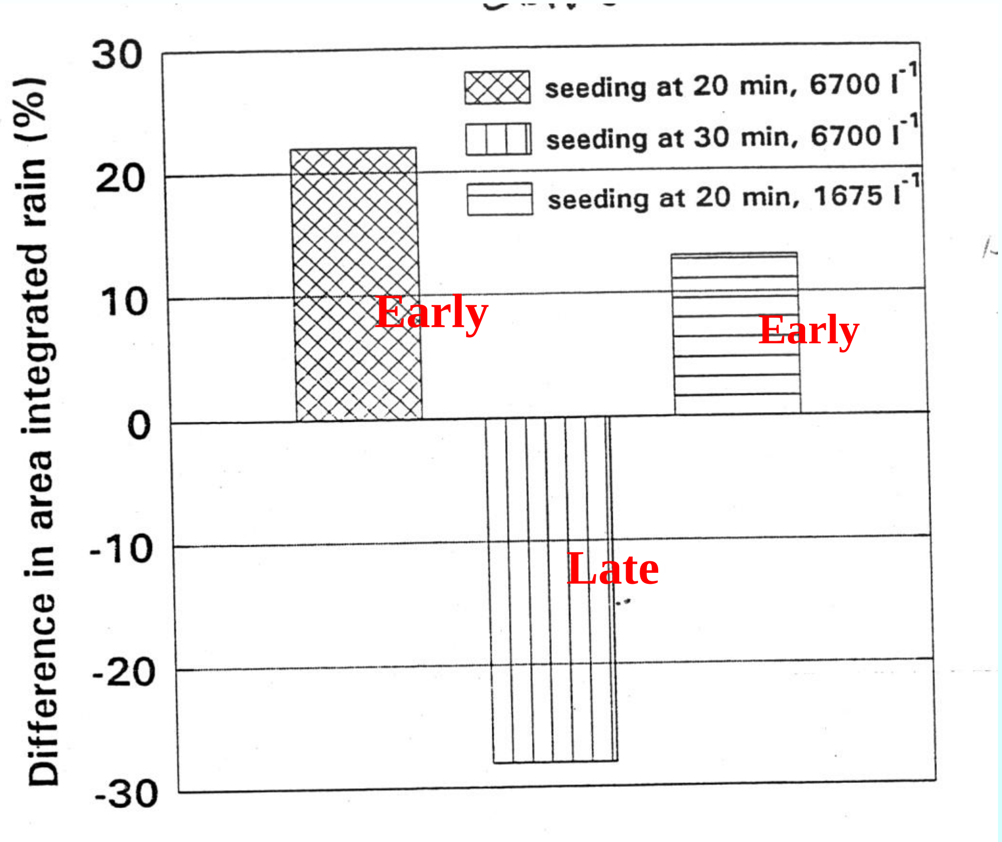
Maritime case (clean)



Mediterranean case (polluted)



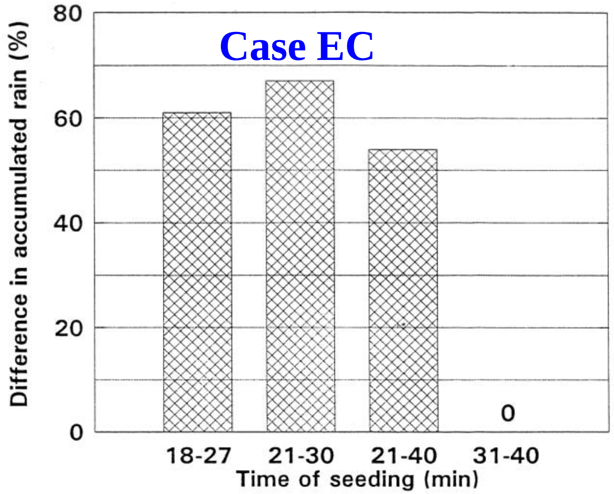
Time of seeding – AgI seeding

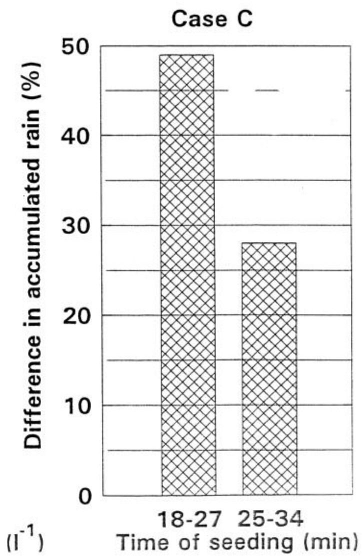


Seeding with high concentrations of AgI nuclei

The effects of seeding time and amount

Time of seeding – Hygroscopic seeding





The effects of <u>seeding time</u> and <u>seeding amounts</u> in Continental (C) and Extreme Continental (EC) clouds

Note that the window of opportunity is larger than in glaciogenic seeding

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Summary and conclusions

- **Use of cloud model in cloud seeding studies:**
  - Concept development
  - Assessment of "seedability" - Potential of cloud to produce more precipitation if seeded.
  - Experimental design
  - Operational decisions
  - Project evaluation
  - Understanding of seeding effect
- **The models show that seeding with AgI or sea salt could be effective if used only in the proper clouds, at the right height and the right time during the development stages of the cloud.**
- **Cloud seeding is not yet a "transferable technology" meaning that prior studies including numerical modeling to characterize the clouds should be conducted in every project.**