Feedback Control of Cumuliform Cloud Formation based on Computational Fluid Dynamics

Yoshinori Dobashi (Hokkaido University)
Katsutoshi Kusumoto (Hokkaido University)
Tomoyuki Nishita (The University of Tokyo)
Tsuyoshi Yamamoto (Hokkaido University)
Goal of Our Research

• Creating realistic-looking clouds with desired shape, based on computational fluid dynamics
• Control of cloud formation process to form the desired shape
• The desired shape is specified by contour line
Overview of Our Method

- Numerical simulation of cloud formation process based on atmospheric fluid dynamics
- Our control method
- Examples
Overview of Our Method

• Numerical simulation of cloud formation process based on atmospheric fluid dynamics
  • Our control method
  • Examples
Simulation of Cloud Formation Process

- Buoyancy force due to the heat from the ground
  - Cooling of the rising air parcels
  - Generation of clouds due to phase transition

Ground is heated by the sun
Simulation of Cloud Formation Process

- Buoyancy force due to the heat from the ground
  - Cooling of the rising air parcels
  - Generation of clouds due to phase transition

Air parcels start to move upward
Simulation of Cloud Formation Process

- Buoyancy force due to the heat from the ground
- Adiabatic cooling of the rising air parcels
- Generation of clouds due to phase transition

Temperature of air parcels decreases

Adiabatic expansion/cooling
Simulation of Cloud Formation Process

- Buoyancy force due to the heat from the ground
- Adiabatic cooling of the rising air parcels
- Generation of clouds due to phase transition

phase transition
(vapor $\rightarrow$ cloud)
Simulation of Cloud Formation Process

- Buoyancy force due to the heat from the ground
- Adiabatic cooling of the rising air parcels
- Generation of clouds due to phase transition

*latent heat* is liberated due to phase transition

(phase transition: vapor $\rightarrow$ cloud)
Simulation of Cloud Formation Process

- Buoyancy force due to the heat from the ground
- Adiabatic cooling of the rising air parcels
- Generation of clouds due to phase transition

*latent heat* is liberated due to phase transition (vapor → cloud)

additional buoyancy
Simulation of Cloud Formation Process

- Buoyancy force due to the heat from the ground
- Adiabatic cooling of the rising air parcels
- Generation of clouds due to phase transition

*latent heat* is liberated due to phase transition

(additional buoyancy)

(further cloud growth)

(phase transition (vapor → cloud))
Simulation of Cloud Formation Process

- Buoyancy force due to the heat from the ground
- Adiabatic cooling of the rising air parcels

**Generation of clouds due to phase transition**

Latent heat is liberated due to phase transition (vapor → cloud) further cloud growth.

Our method automatically adjusts the amount of latent heat to control the cloud growth.
Overview of Our Method

- Numerical simulation of cloud formation process based on atmospheric fluid dynamics
- Our control method
- Examples
Our Control Method

- Feedback controller
- External forces due to potential field

contour line
clouds
Our Control Method

- Feedback controller
- External forces due to potential field

Contour line

Clouds
Our Control Method

- Feedback controller
- External forces due to potential field

minimize difference

contour line
Our Control Method

- Feedback controller
- External forces due to potential field

minimize difference

small difference
small amount of latent heat

contour line
Our Control Method

- Feedback controller

- External forces due to potential field

- Minimize difference

- Contour line

- Small difference → small amount of latent heat

- Large difference → large amount of latent heat
Our Control Method

Feedback controller

External forces due to potential field

Amount of latent heat is automatically adjusted according to difference.
Our Control Method

- Feedback controller
- External forces due to potential field

contour line
Our Control Method

- Feedback controller
- External forces due to potential field

Forces around contour line
Our Control Method

- Feedback controller

External forces due to potential field

forces around contour line

Prevent clouds from growing outside the desired shape
Overview of Our Method

- Numerical simulation of cloud formation process based on atmospheric fluid dynamics
- Our control method
- Examples
Examples

• Computational environment
  – Intel Core2 Extreme X9650
  – 2.0 GB main memory

• Complex cloud shape
  – Simulation grid: 320x80x100
  – Computation time: 7.6 sec per time step
Examples

Same clouds viewed from different position at different time