# SIGMET for Turbulence and Icing
## H. Puempel, WMO

- General Guidelines
- Useful sources of information
- Scientific background
- Feedback and continous improvement

# Responsibility and Scope

- Meteorological Watch Offices
- Regulations: ICAO Annex III, WMO Technical Regulations C 3.1.
- 24/7 Watch to be maintained
- Area of Responsibility: FIR
- Regional Air Navigation Agreements
- Supported by RSMC
- (VAAC, TCAC)

# Use of warning messages

- SIGWX-Charts: WAFS responsibility, intended for flight planning (e.g. avoidance of affected areas & levels), Fixed-time prognostic charts, model-based, coarse resolution
- SIGMET: Actual situation, based on model data, observations (ground based, space based, Pilot Reports), valid for specific time interval, development over time, tendency

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# Purpose of SIGMET

- Provided for flight planning **and** in-flight information (uplink, VHF)
- Warning of actual risk (obs or fcst)
- Clear delineation of risk area & levels, movement, time, intensity of phenomena
- Creates common situational awareness for air crew, operations control, ATM

# SIGMET-Hazards covered by this presentation

- Severe Turbulence
- Severe mountain waves
- Severe Icing

# Causes of Turbulence

- Thermals
- Mechanical turbulence
- Convection
- Clear-Air turbulence
- Shear
- Gravity waves

# Mechanical (terrain-induced) turbulence

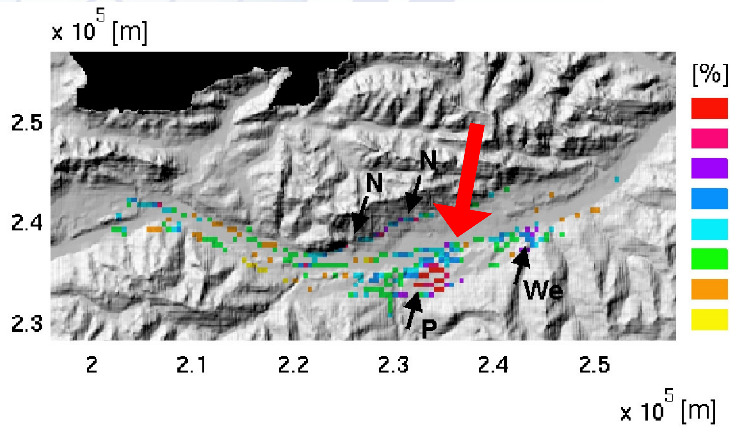
- Typically caused by strong winds over complex terrain
- Stochastic by nature
- May be accompanied by shear effects (gap flows, pockets of stagnant air)
- Requires different pilot action than «typical» wind shear situation
- Could be also addressed by aerodrome warnings,

## Areal Distribution of topographically induced Turbulence

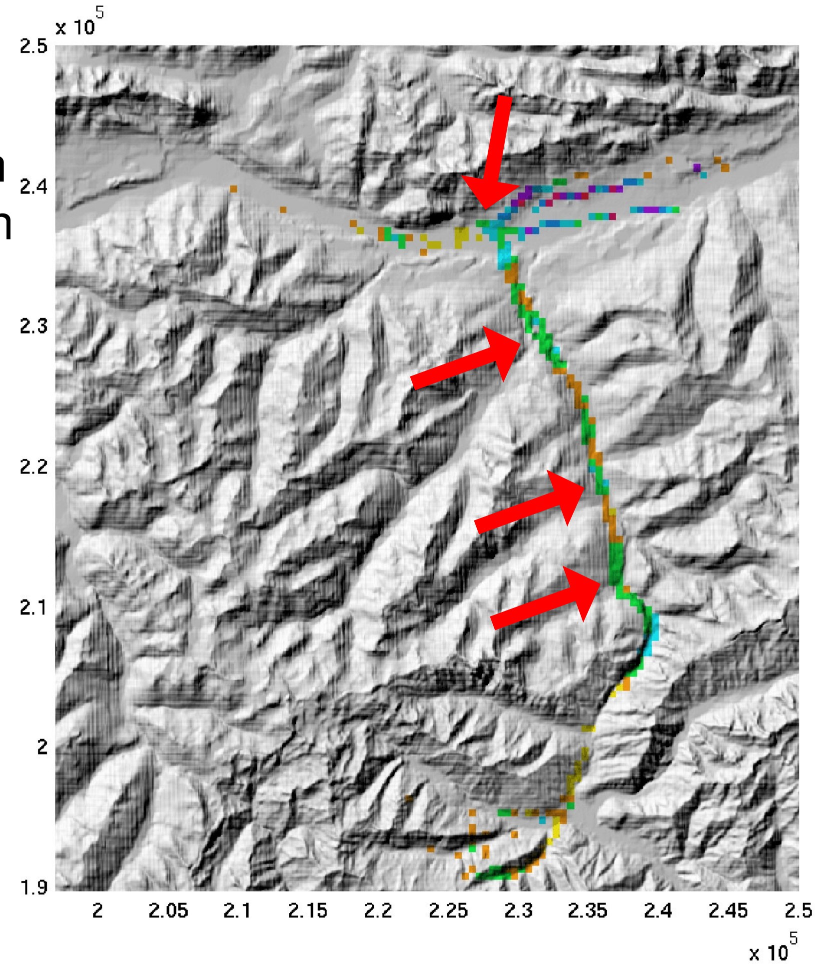
➔ 500 *m* x 500 *m* grid cells with less than five measurements are disregarded.

➔ Grid cells used for the areal distribution calculation of turbulence are weighted with their surrounding ones, in an attempt to minimize statistical errors due to sparse measurements.

06.11.1999




30.10.1999 afternoon flight



# Thermal turbulence

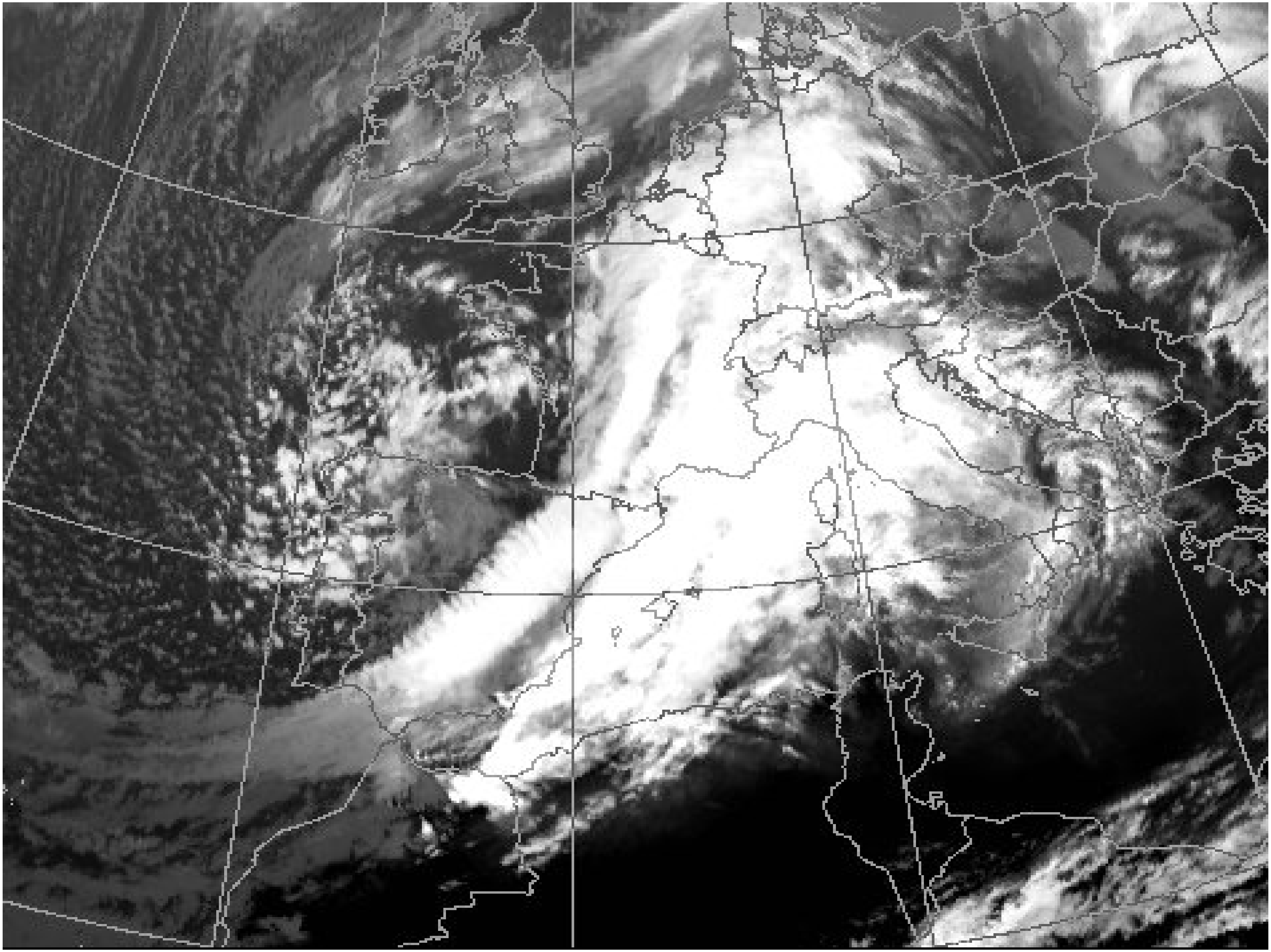
- Rarely reaching the « severe » criterion
- Limited to the planetary bounday layer
- (over high topography, this could well be up to 15.000 ft or higher!)
- In extreme cases, thermally driven flow interacting with topography (gaps, cols) could justify warnings

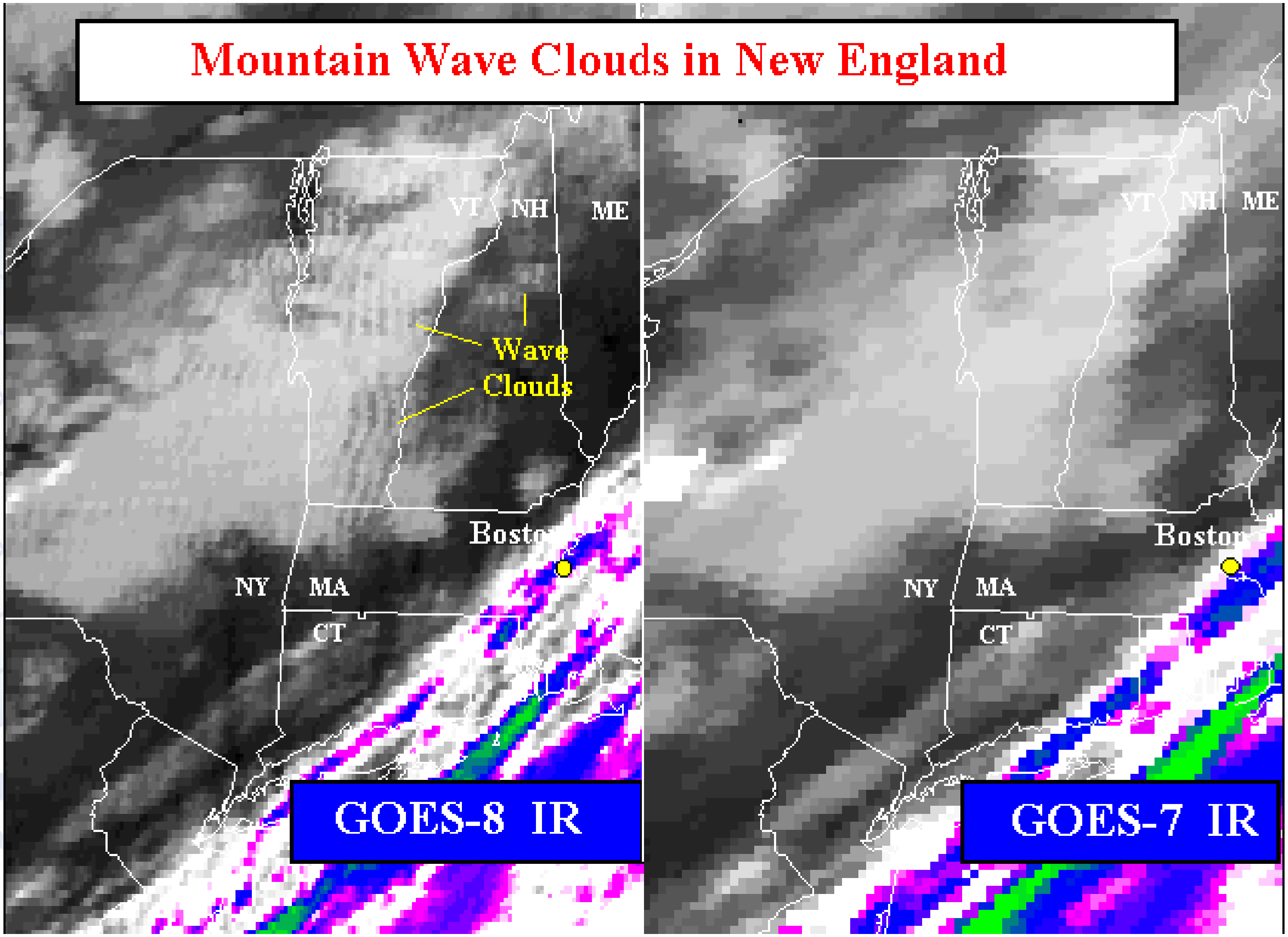
# Convective Turbulence

- Normally covered by SIGMET for EMBD, widespread CB /TS
- Strongest turbulence not automatically related to highest WXR echos (echo-free vault, outflow boundaries, downdrafts potentially channelled by topography
- Important area for user training

# « Clear Air Turbulence »

- Summarizes several related effects
- Unlikely to cause structural damage to aircraft, but:
- Serious injuries to passengers and (cabin) crew still a common problem
- Short-lived and patchy episodes
- Scientifically challenging




Mountain Wave Clouds in New England
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GOES-7 IR

# Mountain Wave turbulence (Bob Sharman et al.)

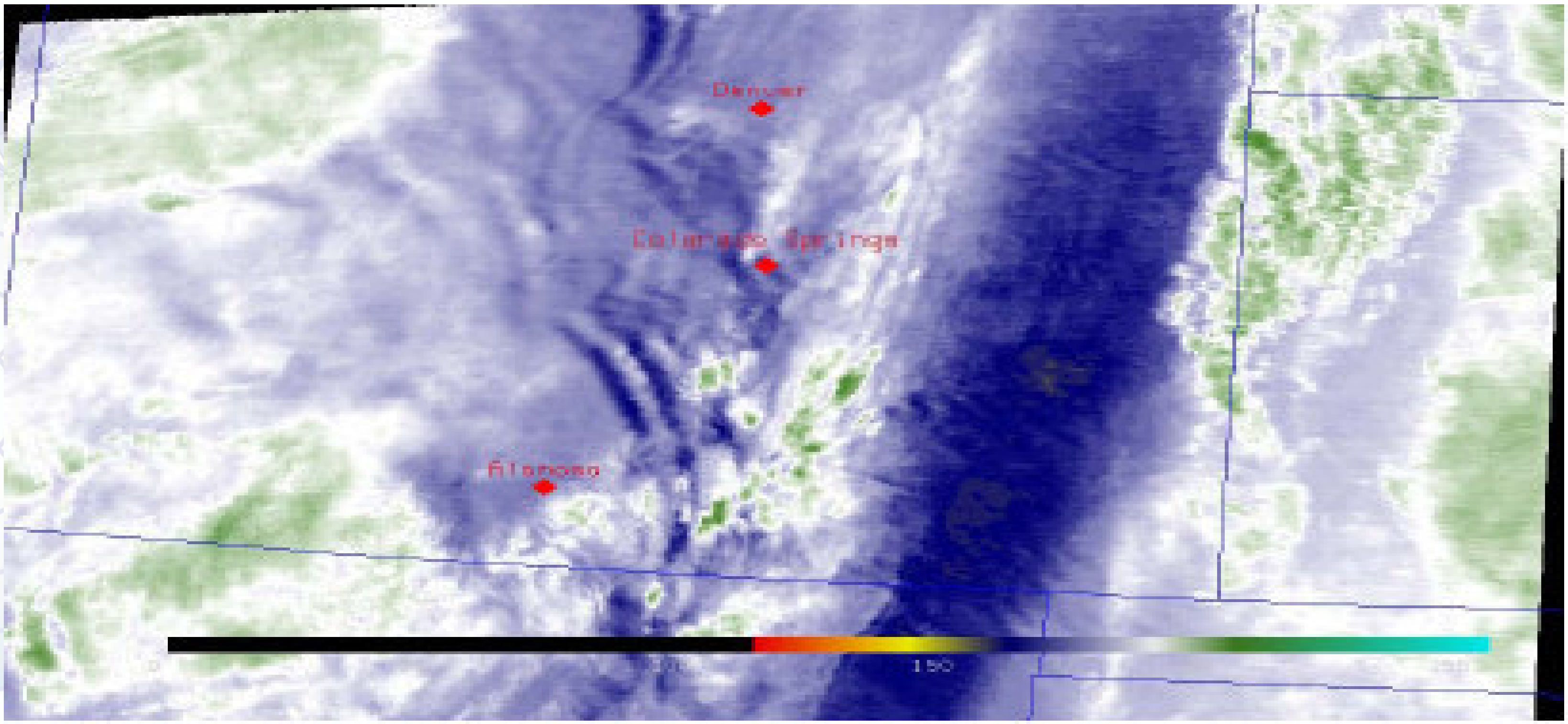


Fig. 1. Water vapor image from MODIS satellite, Feb. 27, 2004 at 0525 UTC. Note the distinct wave pattern northeast of Alamosa, CO.

# In flight Icing cont.

- Icing affects lift (both on main wing and tail)
- Effect depends also on wing profile
- Some rear-mounted jet engines liable to ingest ice removed from wings
- Tail icing often more critical than main wing
- Affects controls, maximum angle of attack
- Aircraft may not be certified to operate in freezing drizzle conditions (drop size >50 mikrons)

# METHODS OF DETECTING SEVERE AVIATION HAZARDS

- Early warning: SIGWX-forecasts from WAFS, regional /high resolution models: guidance for areas where hazards are likely
- Observations (IR, VIS, WV imagery, AMDAR data, Weather Radar, Wind profilers, surface obs, cloud observations)
- Pilot reports ( prompt ATC/ATM to ask Pilots in areas of suspected hazards)

# Gridded Products for Turbulence

- Now available from WAFS FTP service
- Useful to identify potential risk areas
- Very high resolution , non-hydrostatic models needed for detection of mesoscale phenomena (gravity waves, intense shear, interaction with convection /topography)
- Relatively high false alarm rates require cross-check with observations

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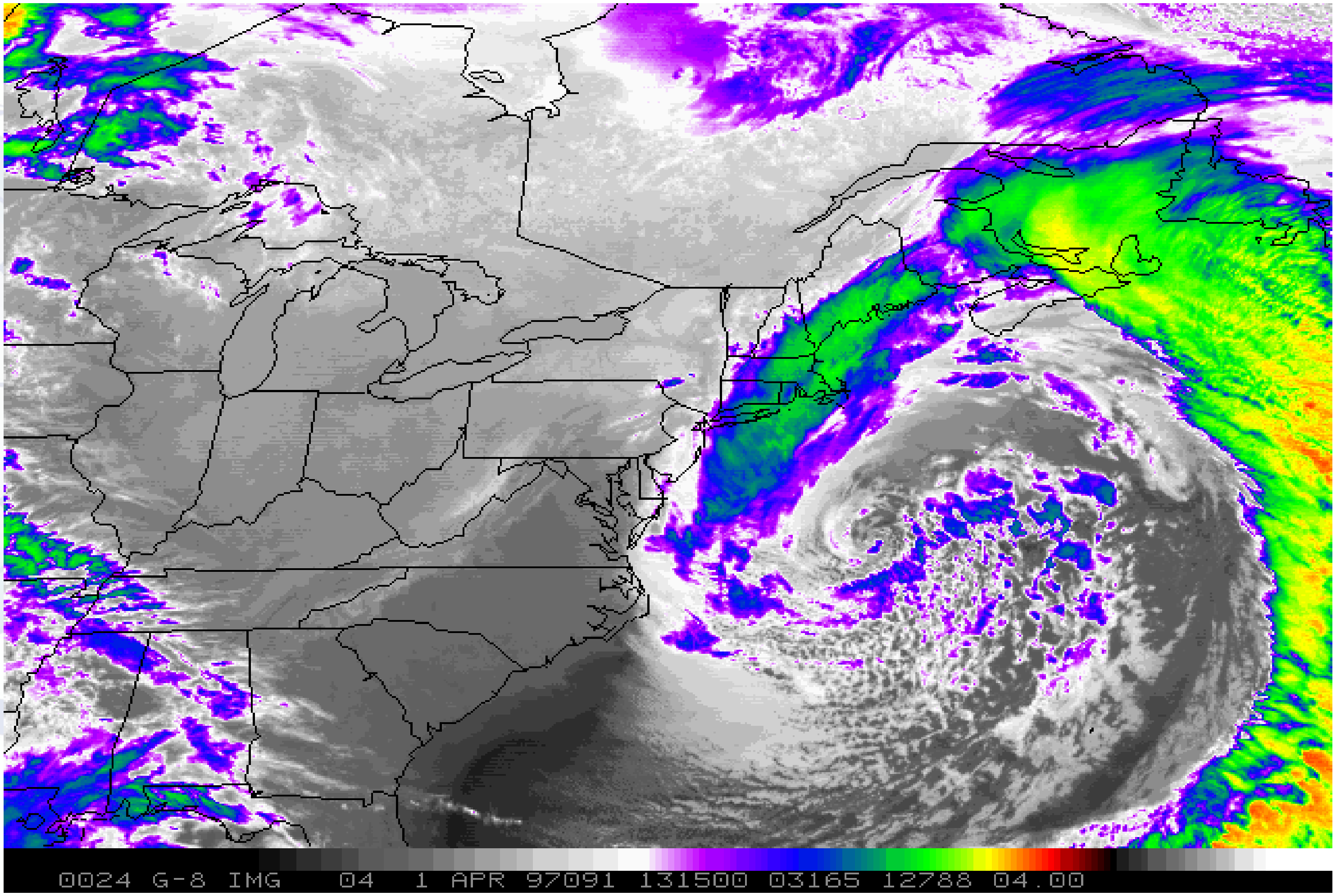
# Turbulence detection by observations

- Space-Based:
  - Identification of jet streams, jet streaks, Kelvin-Helmoltz Instabilities, Divergence and Deformation areas
  - Localization of gravity waves (topographic and convectively triggered)
  - Localization of stratospheric intrusions, indicating strong shear and  and possible gravity wave braking (GWB)
    in WV imagery

# Deformation Zones as CAT predictors

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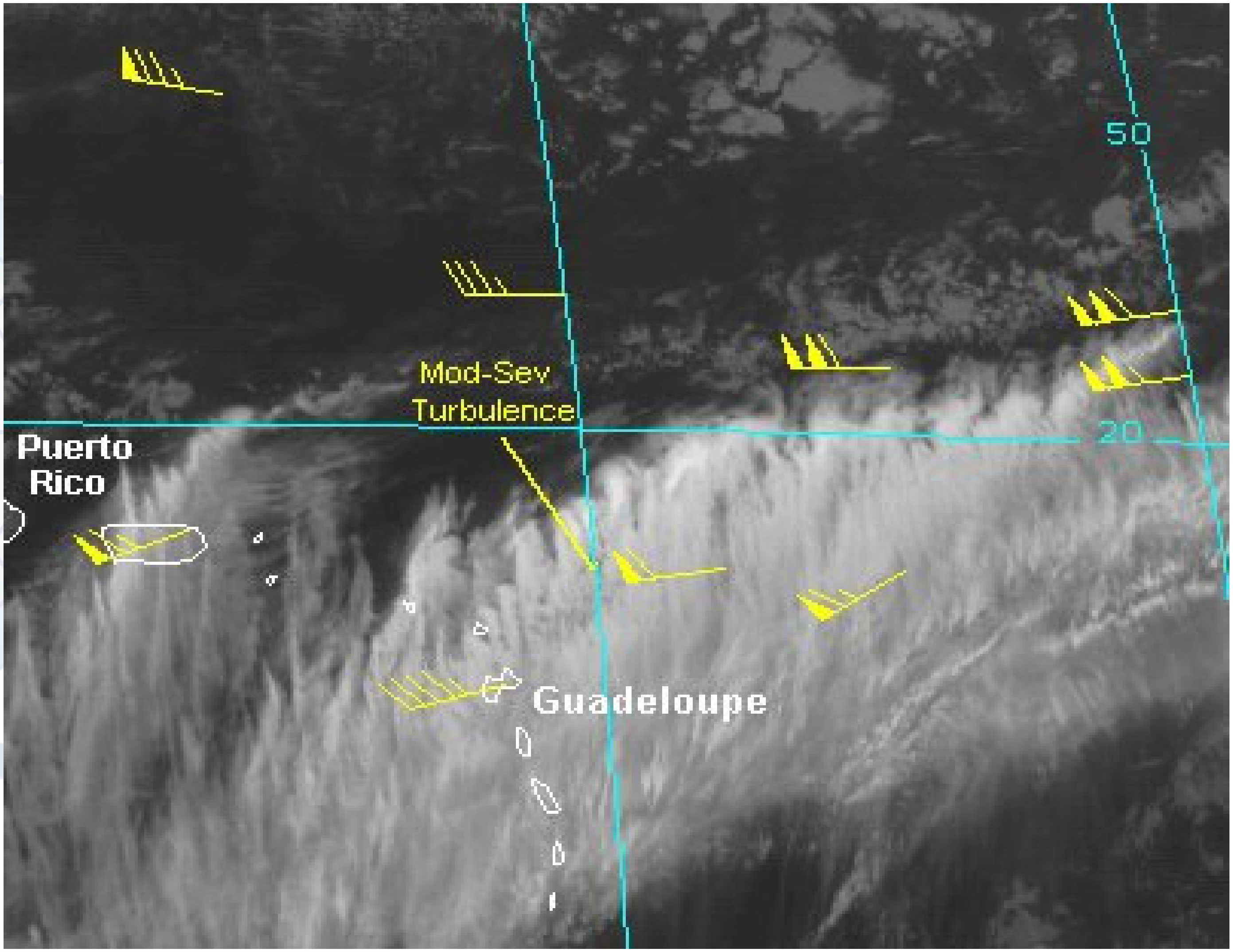
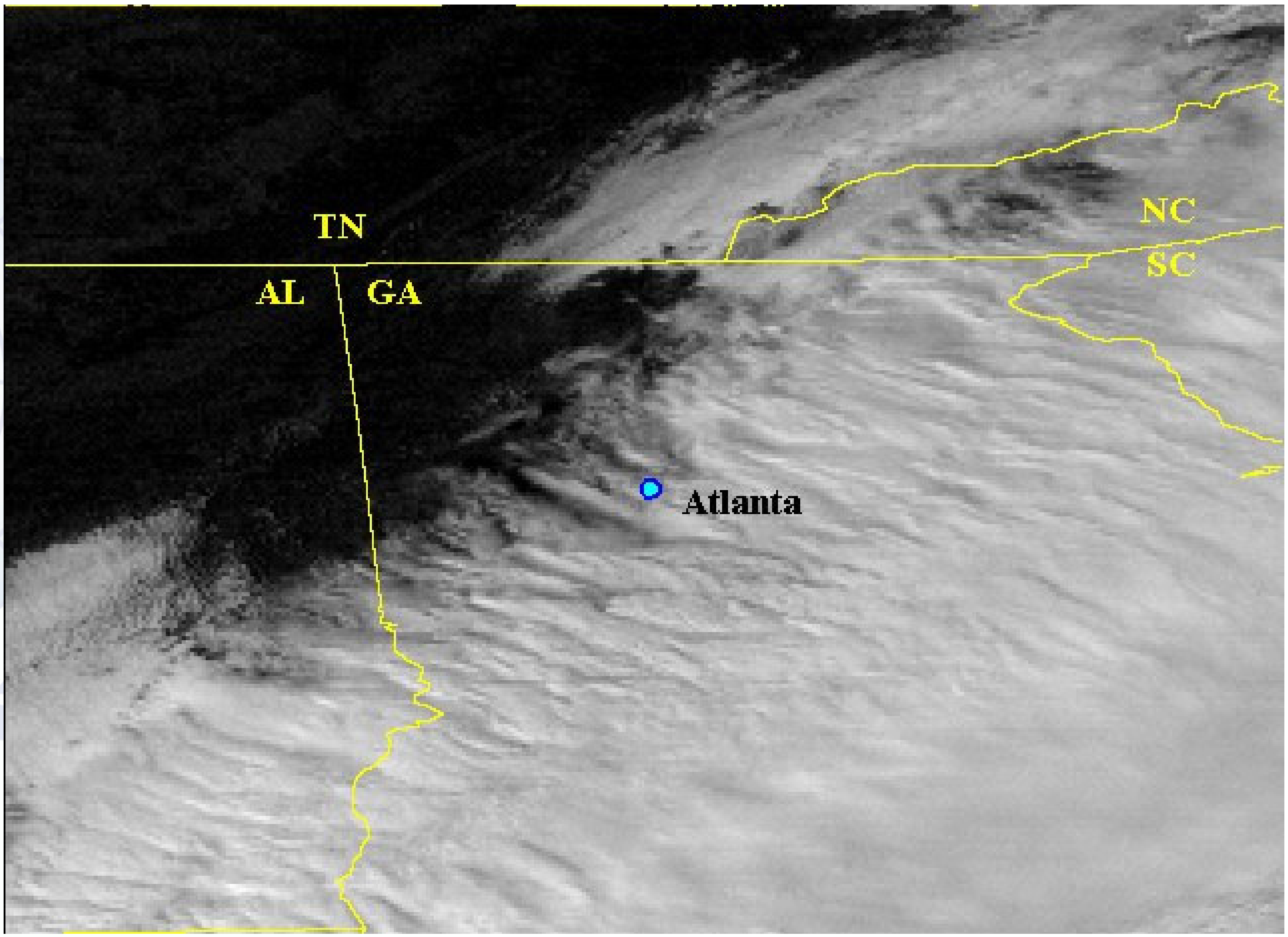
# Banding along Sub-Tropical Jet



# Banding Along Mid-latitude Front



# Extreme Turbulence Scenario

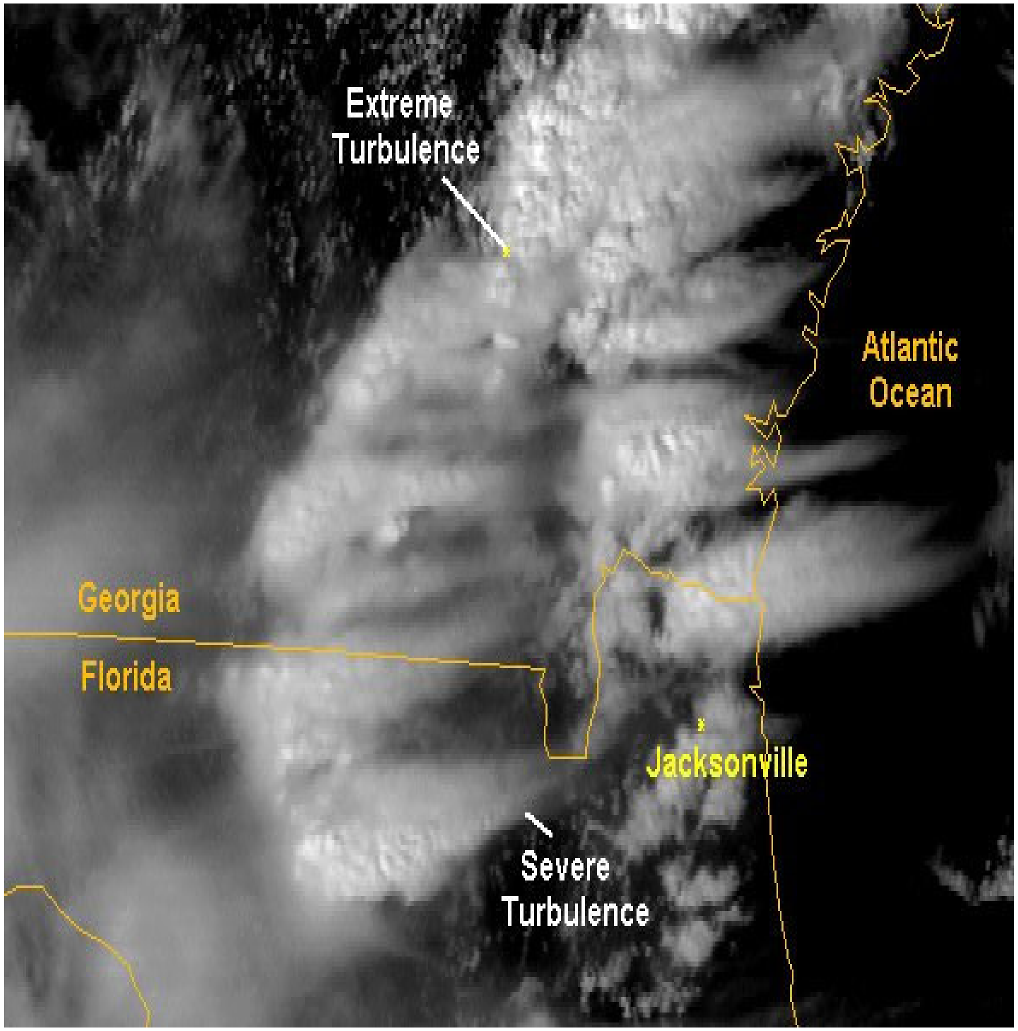
Environmental conditions:

Strong jet intersects:

Cold front with:

Low top convection

Extreme turbulence possible over and downwind from convection



# Mountain waves

- Not limited to large or very high ranges
- (1000ft hills may be enough)
- Trapped vs vertically propagating waves
- Breaking waves potential cause for extreme turbulence
- Trapped waves typically « benign »
- In very strong, long MW danger of overspeed by autopilot trying to hold Flight Level

# Turbulence detection by observations

- Ground-based: Surface pressure drag as indicator for GWB
  - Severe downslope storms
  - Banner clouds, « foehn walls » indicating hydraulic jumps
  - Doppler Radar /Lidar detection of severe storms/shear/turbulence
  - Radiosonde data (wind shear, Richardson Number diagnostics)
  - AMDAR wind data as above

# Scientific basis

- Turbulence: Transition of kinetic energy down the scales (-5/3 law)
- Depending on Richardson Number , stability over square of wind shear
- « Self-elimination » , turbulencacts to reduce wind shear
- Model forecasts of low Ri becoming useful
- Local turbulence « peaks » where sub-grid scale processes decrease Ri-Number

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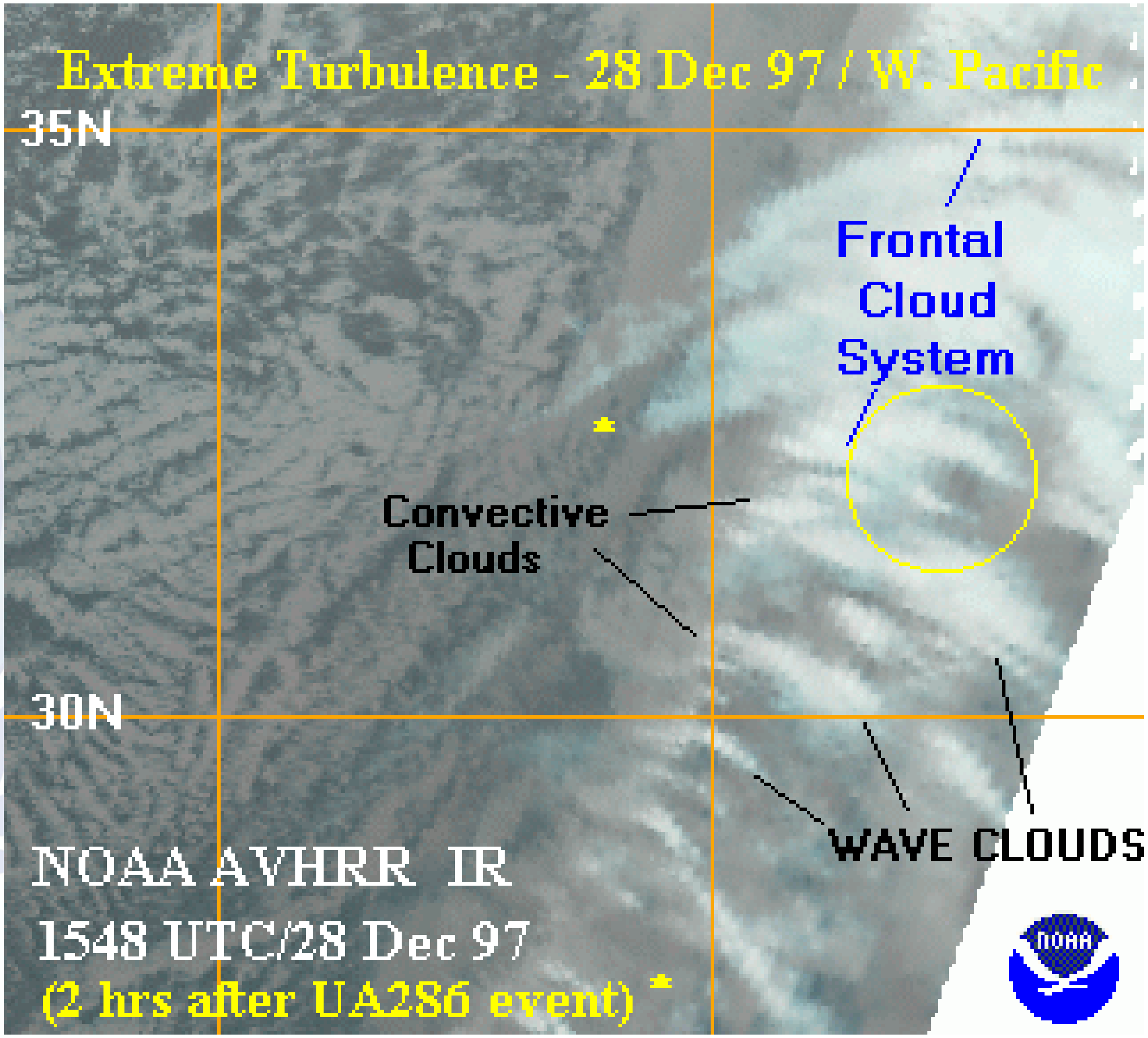
# Trigger mechanisms

- Jet streaks , tropopause folding, stratospheric intrusion (water vapor image!)
- Gravity waves caused by:
  - Orography
  - Vicinity of CB
  - Geostrophic adjustment

# UA286 Turbulence (28 Dec 97)



# In Flight Icing

- Severity dependant on aircraft type, phase of flight, duration of exposure
- Icing in CB covered by Convective SIGMET
- Still highly relevant for smaller, commuter aircraft, but also Jet Airliners at risk (Fokker 70 accidents in Munich and Pau in recetn years
- Highly relevant over high terrain, cold climates

# Detection of Icing Potential

- Models: Icing products generated by many NMS's and institutions (CIP/FIP in US, UKMO, Meteo France, DWD to name but a few)
- Require complex model physics (ice phase, preferably aerosol content, convection)
- Intensification of Icing Potential by mesoscale processes (rainbands, complex topography) difficult to reproduce

# Known strengths and weaknesses of current algorithms

- Reasonable detection of hazard areas
- Tend to overforecasting affected area in some models
- Great difficulties in discerning between lgt/mod and severe (resolution of liquid water content!)
- Drops size distribution not well modelled
- Projection of enhanced icing in mesoscale phenomena to lowest resolvable scale
- Some models exaggerate « scavenging » of liquid water by ice crystals

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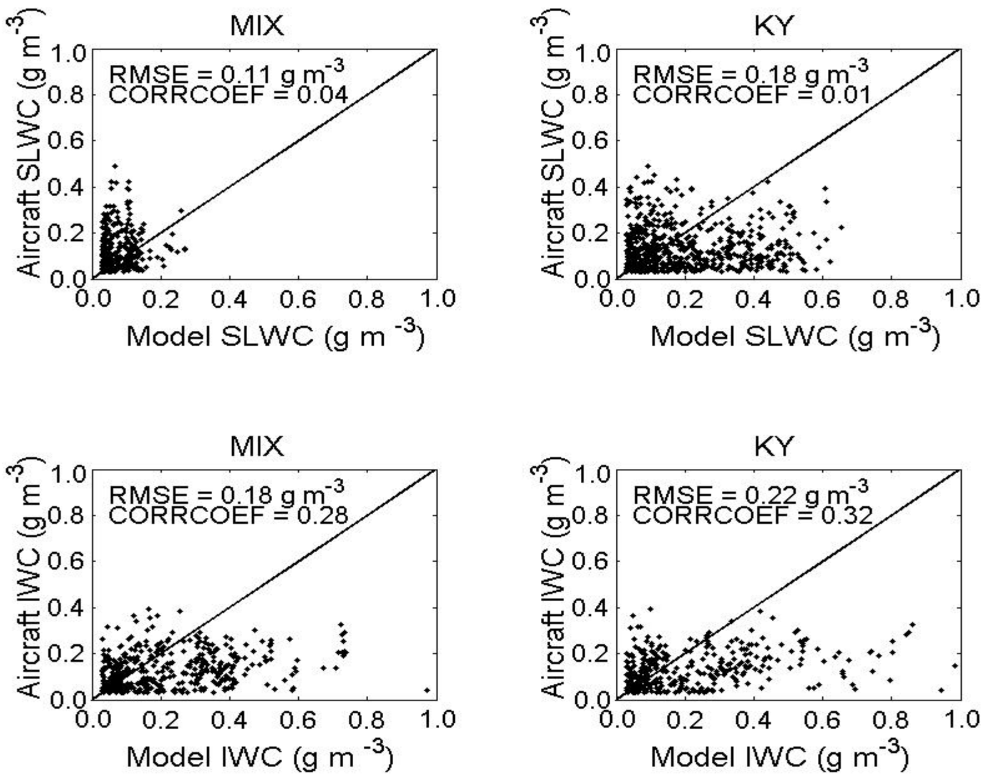
# G.Isaac (Montreal):Comparison of measured and forecast liquid water contents



# Detection of Icing Potential -Obs

- « Classical » Appleman –Mori from Radiosondes – spacing and time gap often too large to detect mesoscale bands
- Space-based: in the absence of cirrus above, presence of ice crystals detectable by split-window technique
- For low-level FZDZ surface obs very useful
- PIREPS!!!!

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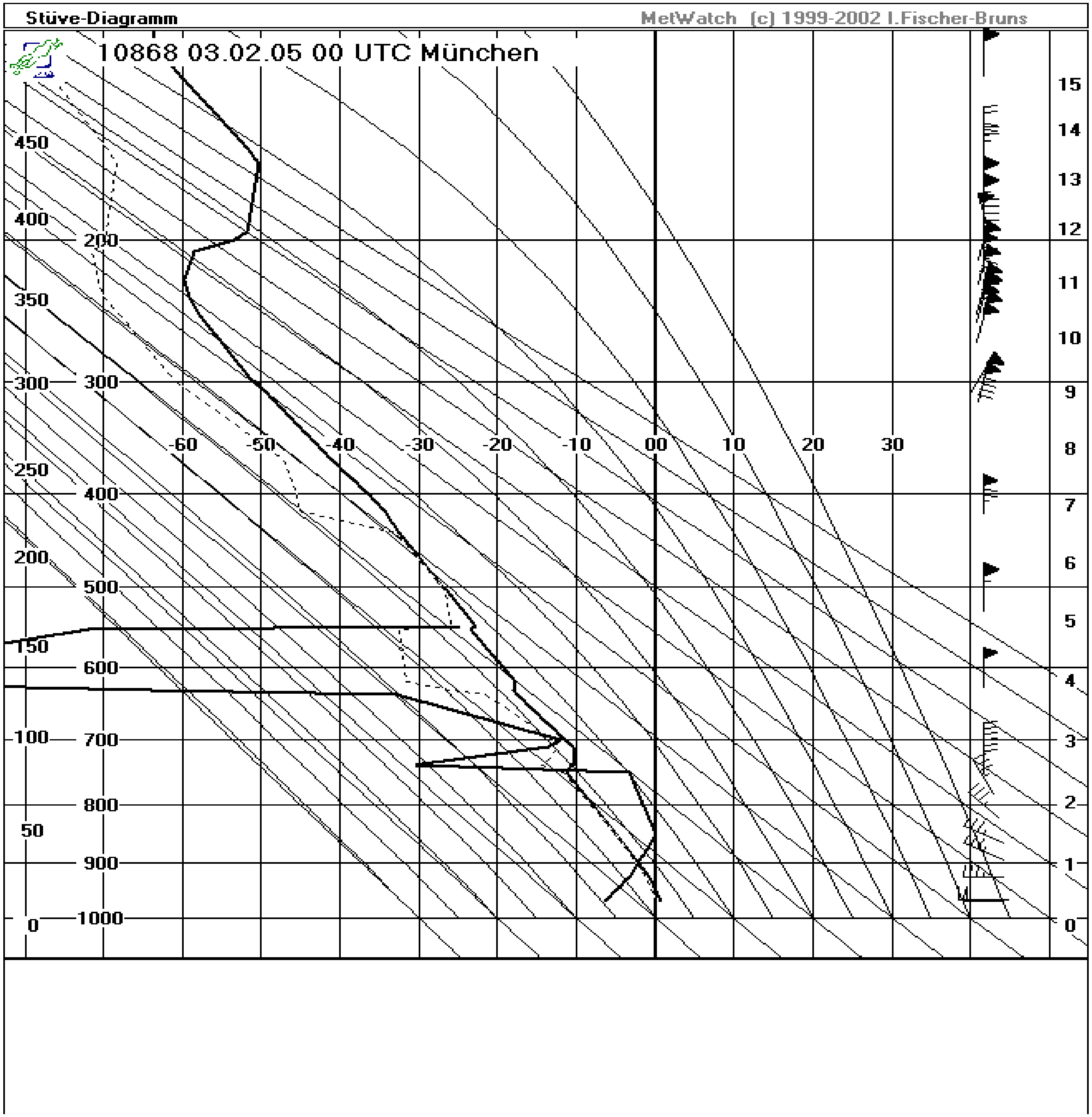

Stüve-Diagramm
MetWatch (c) 1999-2002 I.Fischer-Bruns
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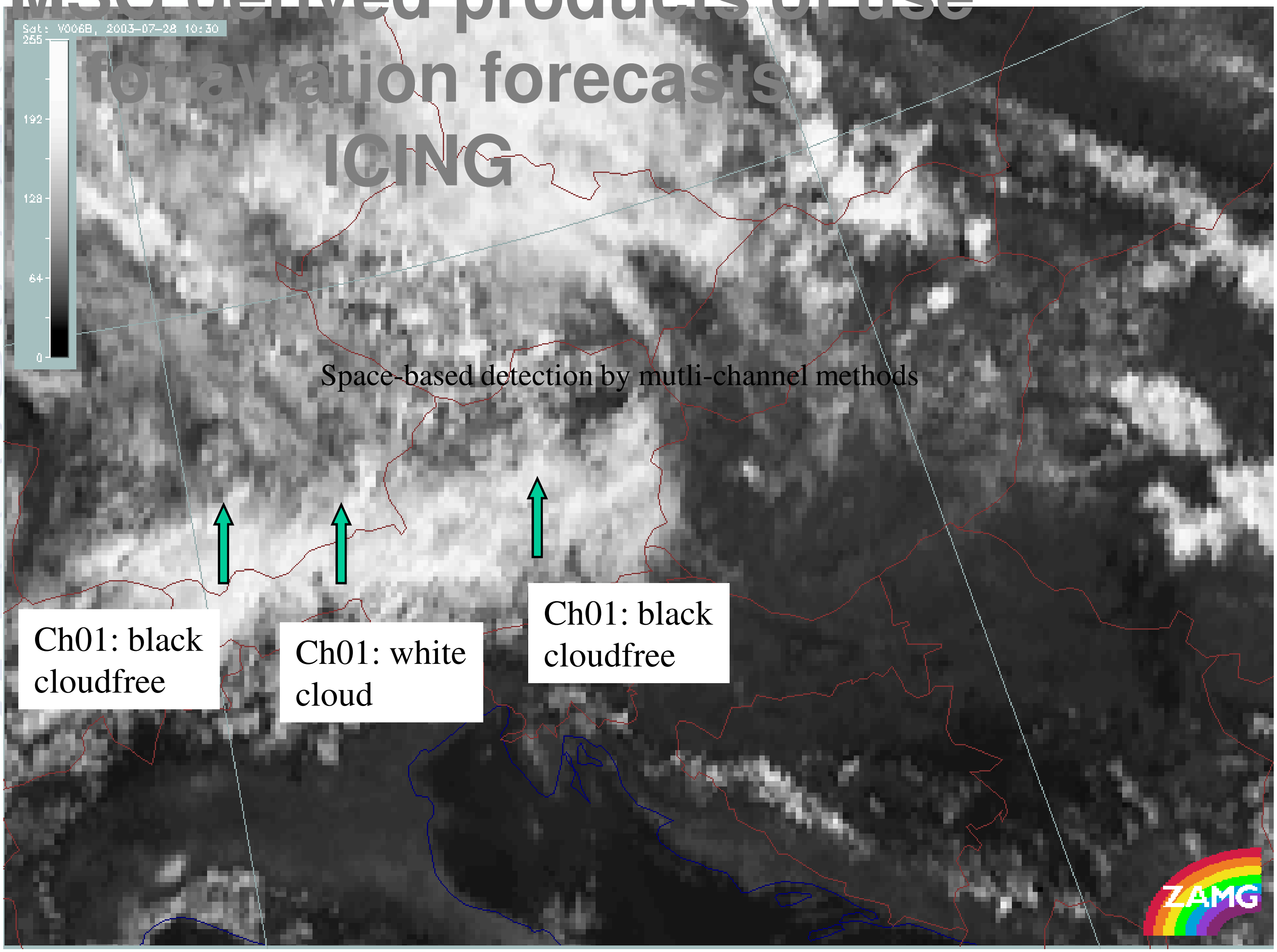
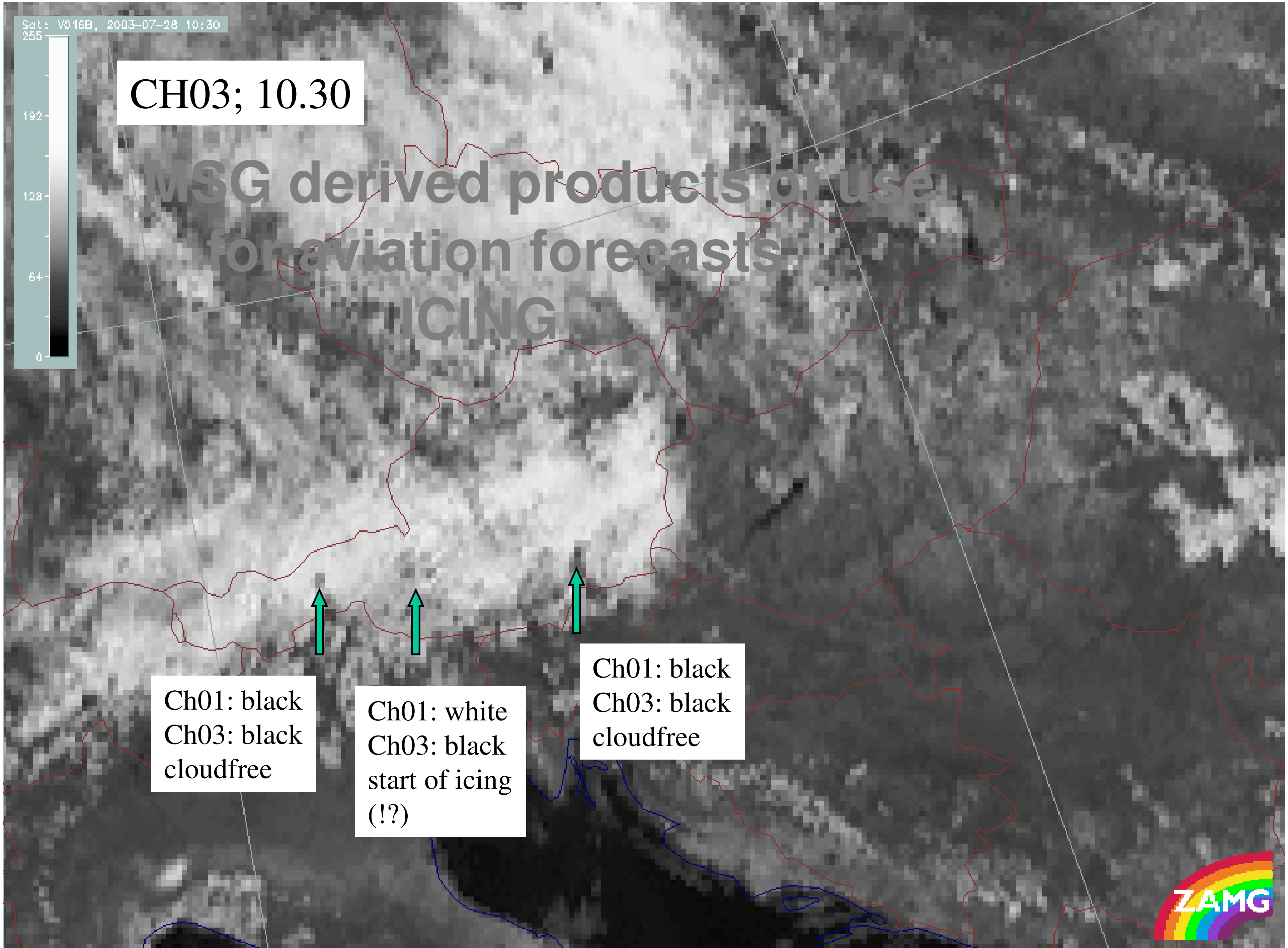
# MSG derived products of use for aviation forecasts ICING




Space-based detection by mutli-channel methods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Ch01: black
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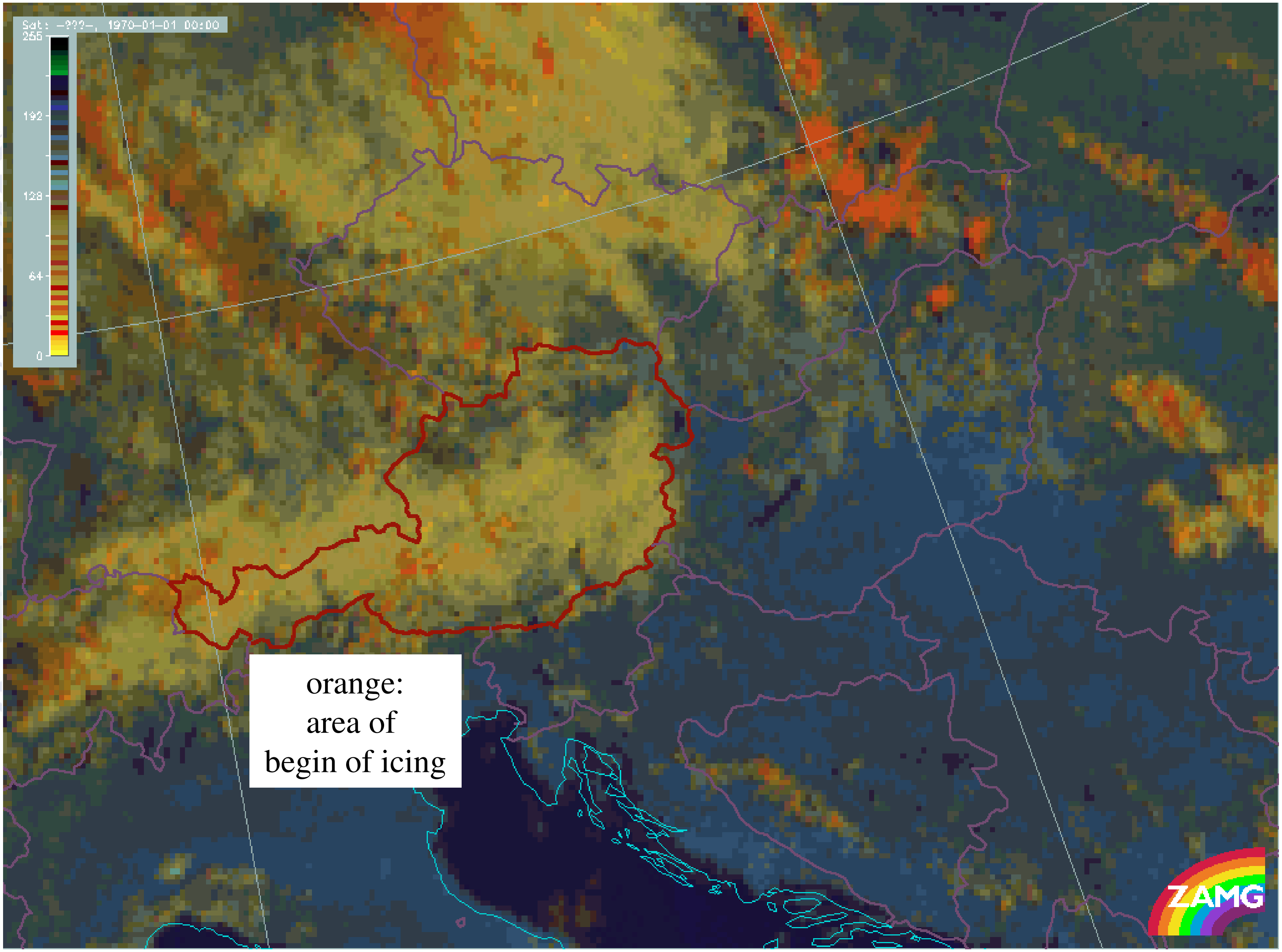
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# Severe Icing

- Limited temperature range (typically - 10 to - 4 C)
- Liquid Water Content > 0.5 g/kg
- Large droplets present (>50 mikrons)
- No or at least little « scavenging » by ice crystals unless compensated by massive vertical advection of moisture!!!
- Local intensification by:
  - Topography
  - Banding
  - Warm advection
  - Lack of suitable condensation kernels

# Acknowledgements

- Thanks to NOAA (G. Ellrod, R. Sharman,S. Koch), P. Malcher (UIBK), KNMI, ZAMG, UKMO

  for their pioneering work and permission to use training material!

Excellent modules in E and S to be found at:

http://www.meted.ucar.edu/topics_aviation.php

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