Emerging Needs of Turbulence Guidance

For Increasing Non-Traditional Flight Operations

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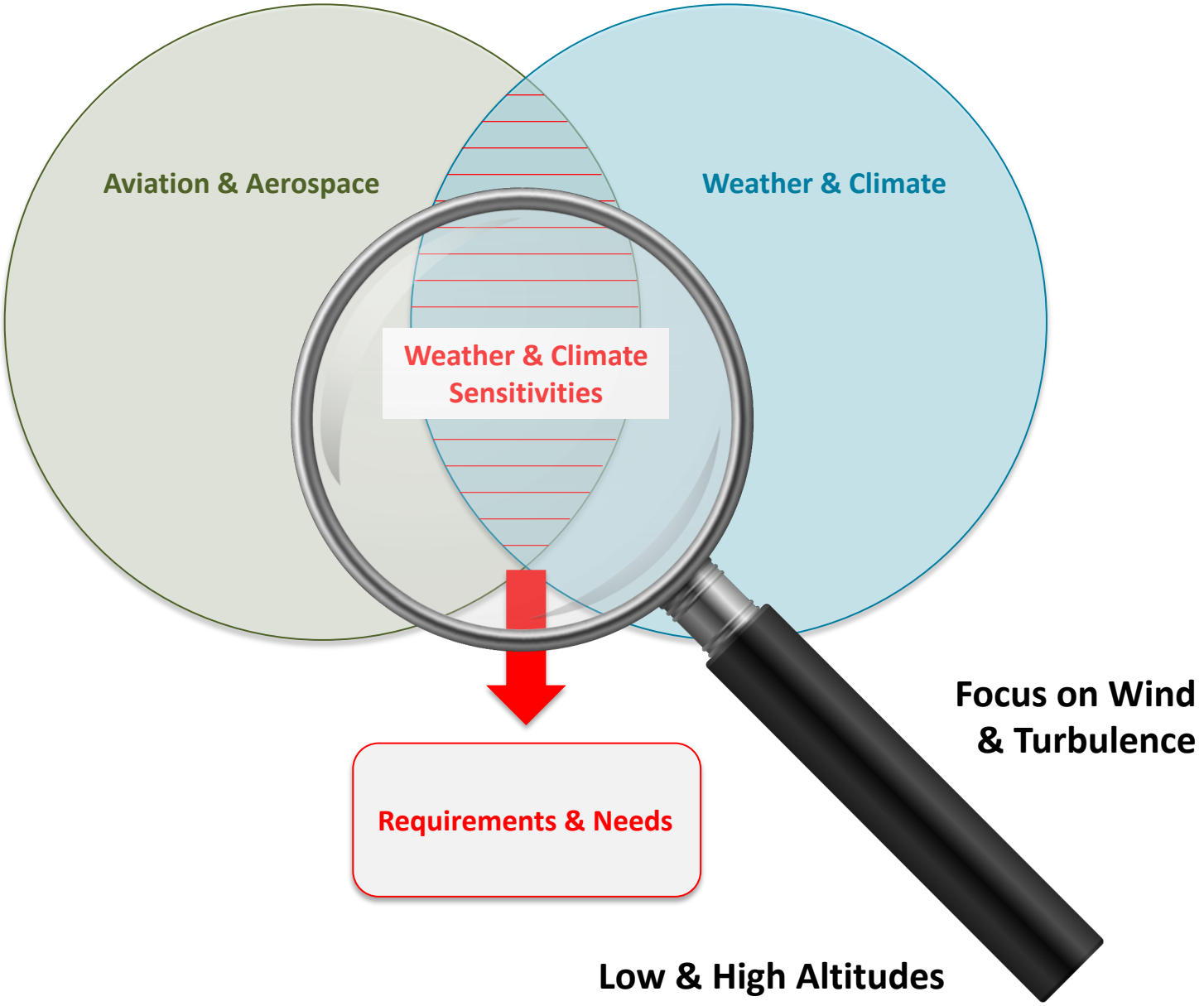


Evolving Aviation & Aerospace Industry

Low-altitude operations

- Advanced air mobility (e.g., UAS, UAM)
- Wide variety of aerial vehicles & mission profiles

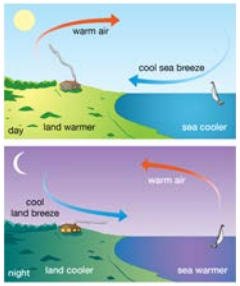
Evolving Aviation & Aerospace Industry

High-altitude operations

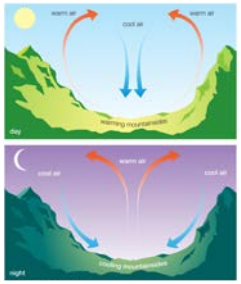
- Space launch & reentry
- Super/hypersonic travel
- Balloons & pseudo-satellite UAS

Weather & Changing Climate

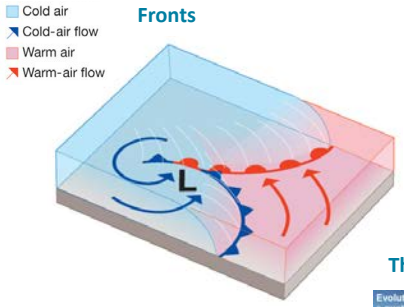
Land/sea breezes



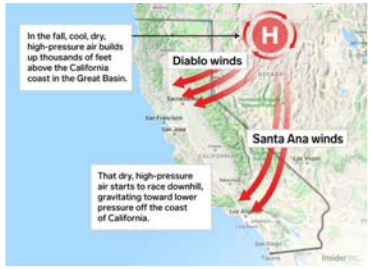
Mountain/valley breezes



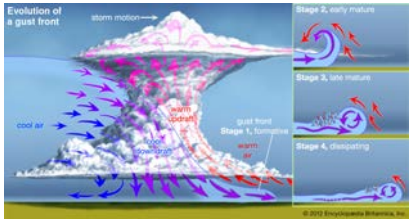
Fronts



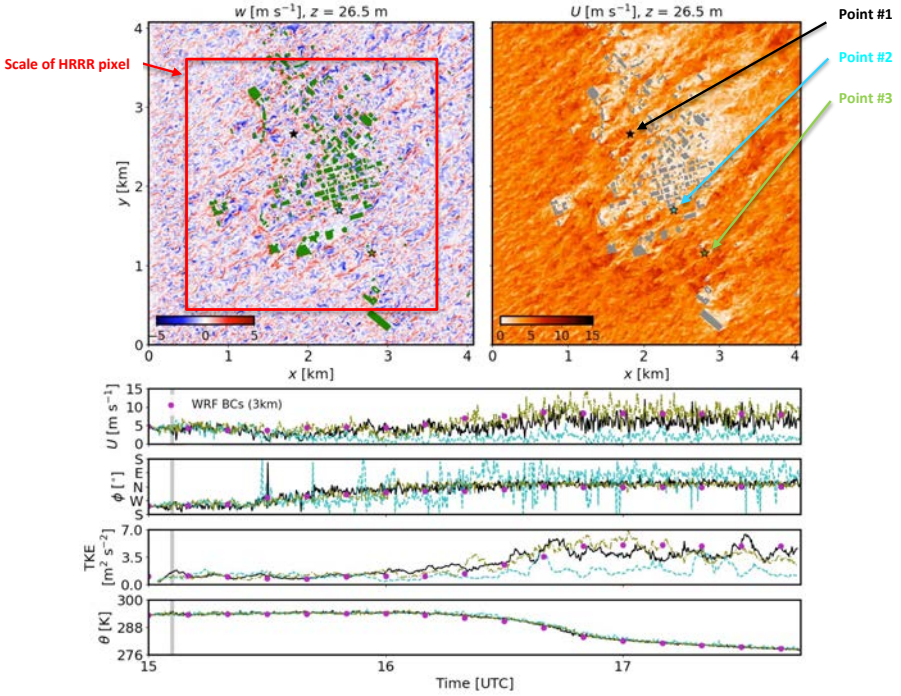
Downslope windstorms



Thunderstorm dynamic



Urban dynamics based on NCAR's FastEddy model



Muñoz-Esparza et al. (2021)

Boundary layer

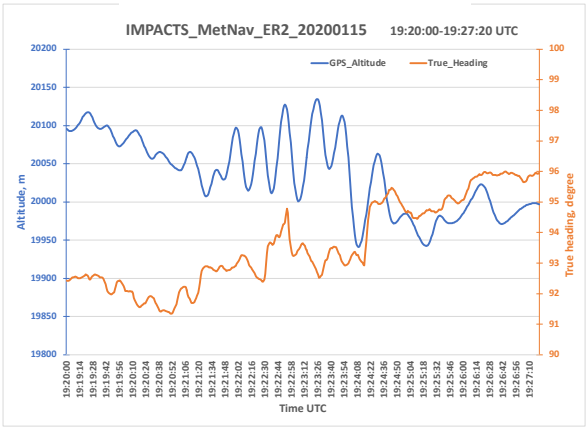
- Particularly dynamic in lowest levels of atmosphere
  - wide range of processes & scales yield variable wind & turbulence
- Less predictable at high resolution & specific locations
  - especially in complex environments, like urban landscapes

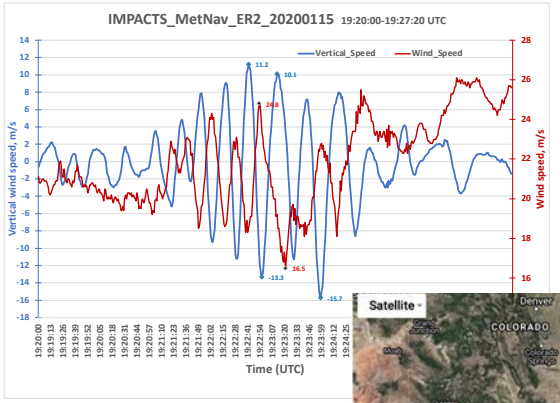
Weather & Changing Climate

Stratosphere

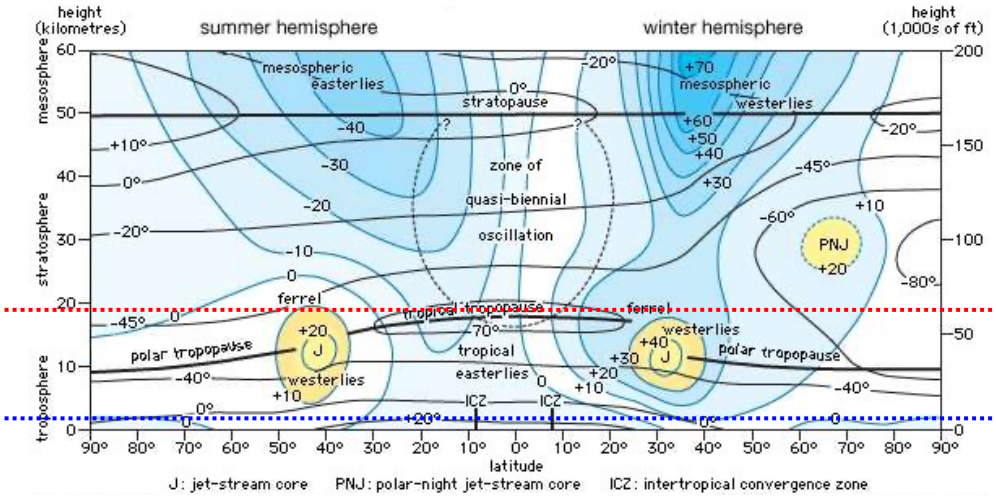
- Varying tropopause height
  - 9 km at poles, 16-17 km in tropics
- Seasonally changing wind regimes
- Hazardous conditions may result from
  - rapidly changing wind conditions
  - vertical propagation of gravity waves generated by mountains or thunderstorms
  - turbulence from breaking waves or dynamic shear instabilities

Significant wave encounter by ER-2





Meridional cross section



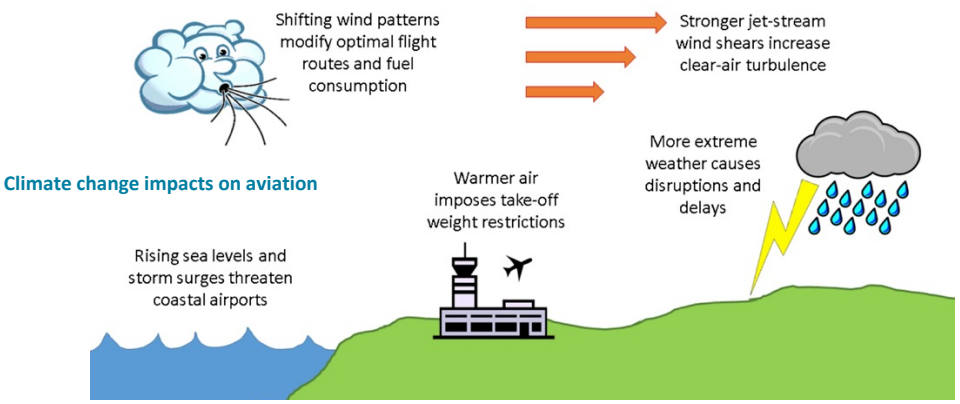
Encyclopedia Britannica (2008)

Upper Class E Airspace

Traditional Airspace

UAS, UAM, etc.

Weather & Changing Climate



Climate change impacts on aviation

ICAO (2016)

Climate risk	Impact	Actors
Precipitation change	■ disruption to operations e.g. airfield flooding, ground subsidence ■ reduction in airport throughput ■ inadequate drainage system capacity ■ inundation of underground infrastructure (e.g. electrical) ■ inundation of ground transport access (passengers and staff) ■ loss of local utilities provision (e.g. power).	
Temperature change	■ changes in aircraft performance ■ changes in noise impact due to changes in aircraft performance ■ heat damage to airport surface (runway, taxiway) ■ increased heating and cooling requirements ■ increased pressure on local utilities e.g. water and power (for cooling).	
Sea-level rise	■ loss of airport capacity ■ impacts on en-route capacity due to lack of ground capacity ■ loss of airport infrastructure ■ loss of ground transport access	
Wind changes	■ convective weather: disruption to operations ■ convective weather: route extensions ■ jet stream: increase in en-route turbulence ■ local wind patterns: disruption to operations and changes to distribution of noise impact	
Extreme events[1]	■ disruption to operations, route extensions ■ disruption to ground transport access ■ disruption to supply of utilities	

[1] *sudden intense and short-lived precipitation and wind events e.g. storm surges, hurricanes, hail storms, lightning as opposed to seasonal or annual changes*

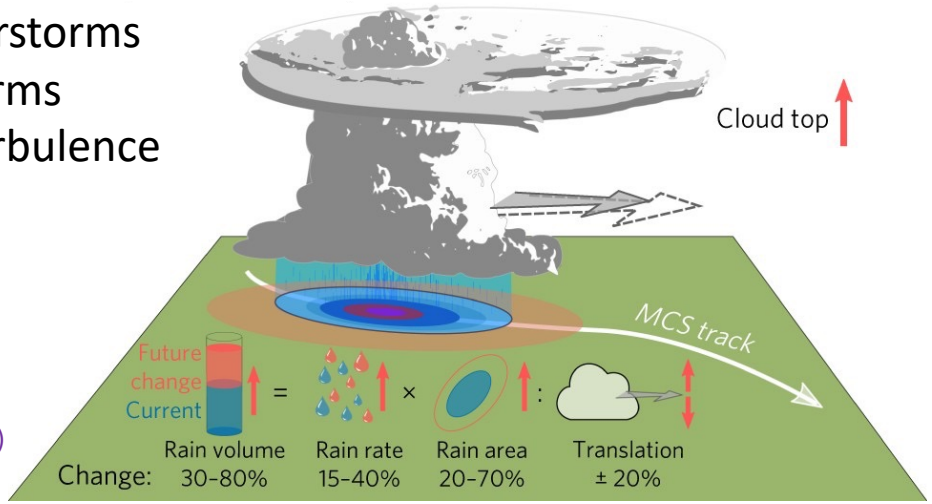
Aircraft operators · Airport operators · ANSP · External

Evolving climate system

- Intensifying jet stream
  - stronger winds & turbulence
- More frequent & intensifying thunderstorms
  - changing storm tracks & deeper storms
  - more lightning, hail, rain, wind & turbulence
- More heat waves & drier conditions
  - reduced lift for takeoff
  - increased low-level turbulence
  - increased wildfires & pyrocumulonimbus

Prein et al. (2017)

Expected changes in MCS characteristics



Emerging Requirements & Needs

Weather sensitivities

- Specific to type of aerial vehicle & mission
  - need to understand performance limitations & mission aspects
- Controllability under windy & turbulent conditions
  - safety of flight, platform stability, fuel/energy management, wake vortices, etc.
- Infrastructure & operational resilience to weather impacts
  - airlines learned how to cope with weather impacts – how about new entrants?

Weather guidance

- Limited routine weather guidance for low- & high-altitude operations
- Predictions build upon scientific understanding of environment
  - need more observations in boundary layer & stratosphere
  - need to understand requirements for spatial & temporal resolution, refresh rate, look ahead times, etc.
  - predictability limits may require probabilistic forecasting
- Responsibility for providing necessary weather guidance

Regulatory aspects

- Certification of novel aircraft
  - automation & autonomy rely on sensed data & algorithms

Summary

Key Points

- Aviation/aerospace industry is evolving rapidly
- Novel & resurgent operations exhibit unique weather sensitivities
- Improved weather guidance needed to support these emerging operations
- Scientific understanding of low & high altitude operational environments necessary to develop actionable weather guidance
- Environmental challenges must inform aircraft design & certification, operational procedures & regulations, training, etc.
- Evolving climate will likely amplify existing & bring new weather challenges for operations & infrastructure

Resilient Operations

- Need to focus on enhanced predictability, efficiency, reliability & sustainability of aviation operations
- Weather needs to be an integral part of infrastructure & operations planning, & decision making
- Collaboration across disciplinary boundaries is essential for developing effective solutions

- Agile prototyping & testing beneficial to accommodate evolving industry needs

Questions?

The views expressed are those of the presenter and do not necessarily reflect the position of the funding agencies.

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