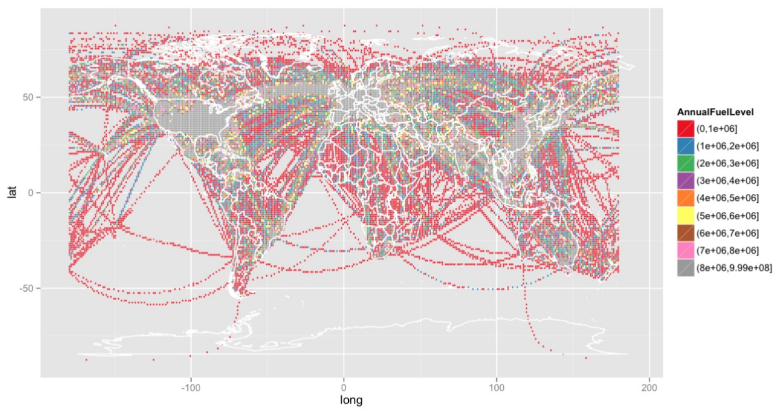
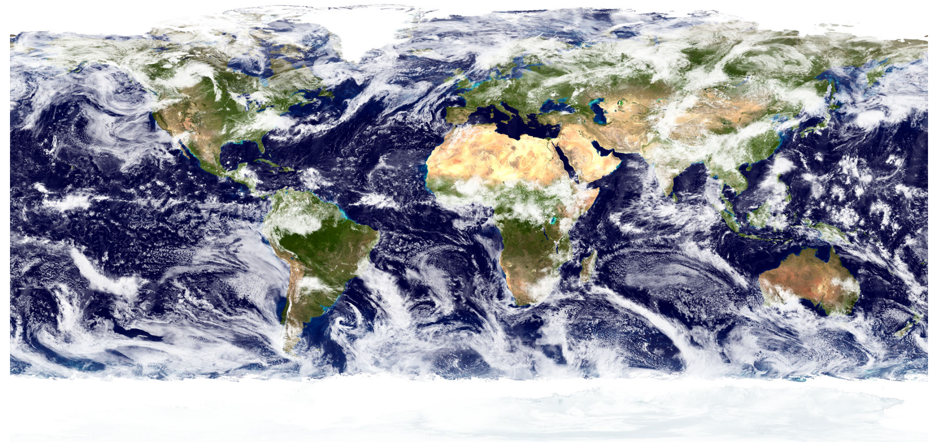




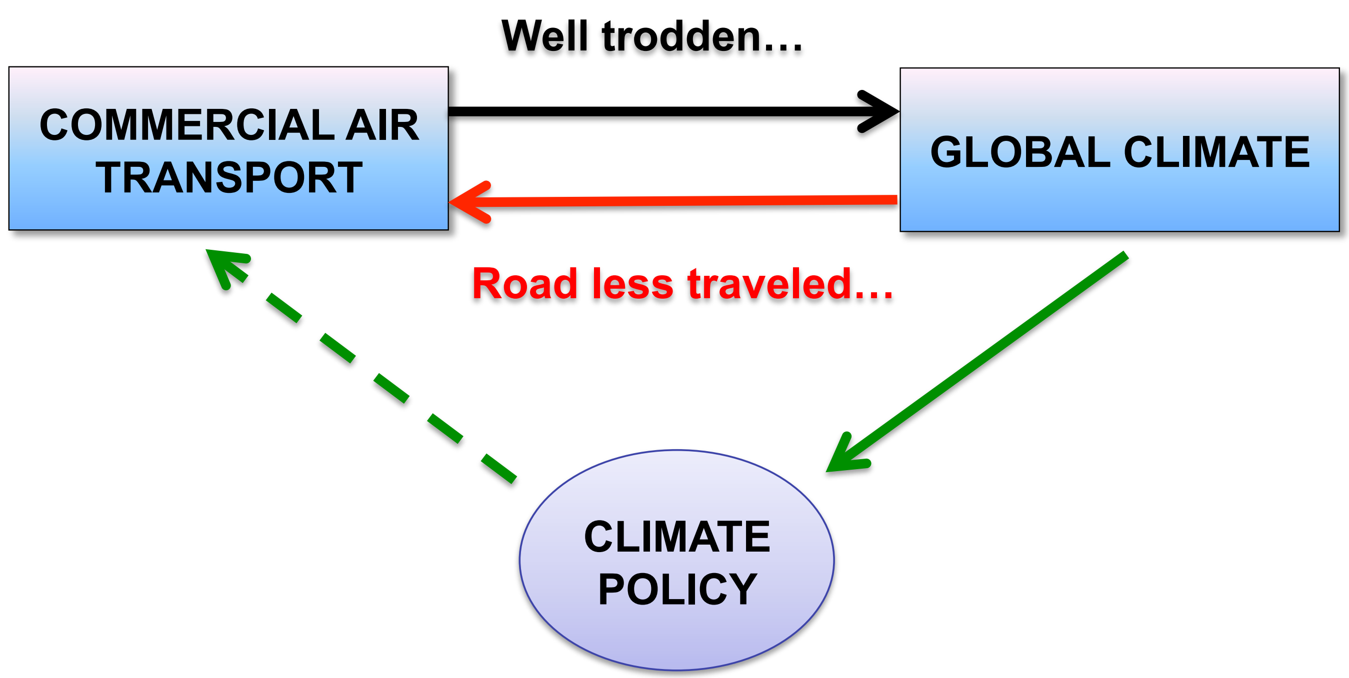
Climate Services Needs in the Air Transport Sector

Terence R. Thompson

January 2015

LMI

Air Transport and Climate - Context



Climate Impacts on Commercial Air Transport

- Airports
- Aircraft and engines
- Airspace
- Passenger safety and comfort
- Atmospheric effects (CO_2, water/ice, NOx, SOx, PM)
- Shifts in passenger travel preferences
- Future air-transport concepts
- Public perception

Physical Effects Linked to Different Aspects of Business Performance

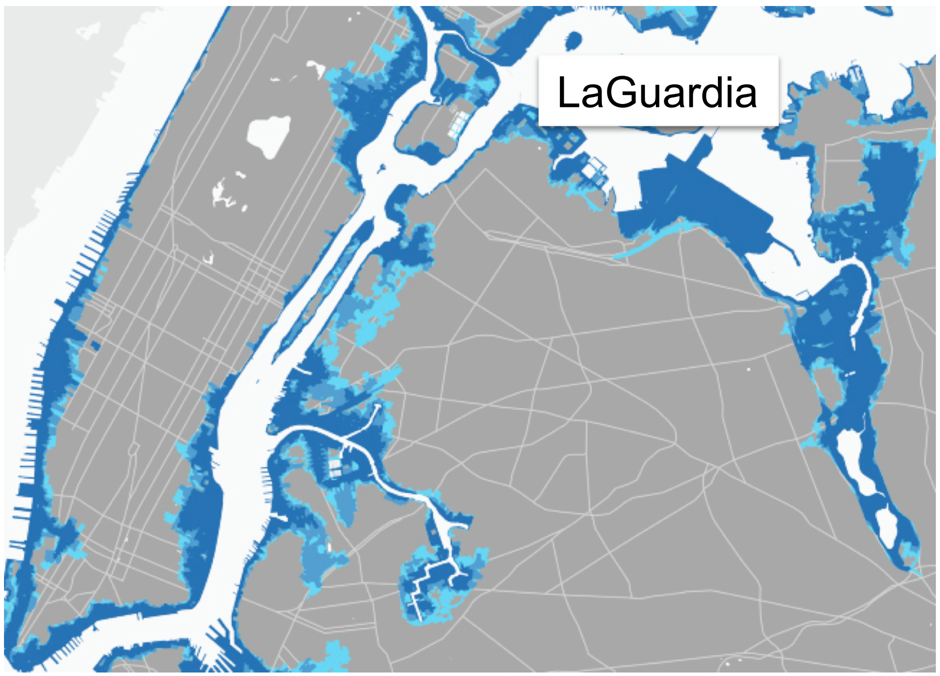
Climate Effect	Infrastructure	Aircraft Performance	Passenger and Cargo Demand	Flight Safety	Passenger Comfort	Environmental Impact
Temperature increase	Heat damage to runway/taxiway surfaces	Decreased climb performance	Shifts in geographic region and season	-	-	Changes in noise impact
Change in precipitation	Loss of efficiency, increased delays	-	Shifts in geographic region and season	-	-	Changes in air-quality impact
Frequency and intensity of convective weather	Loss of efficiency, increased delays	-	-	Increased turbulence, etc.	Increased turbulence	-
Changes in wind patterns	Loss of efficiency, increased delays	-	-	Increased crosswinds	-	Changes in air-quality impact
Sea-level rise, increased storm surge	Intermittent or permanent airport closures, loss of efficiency, increased delays	-	Shifts in geographic region and season	-	-	-

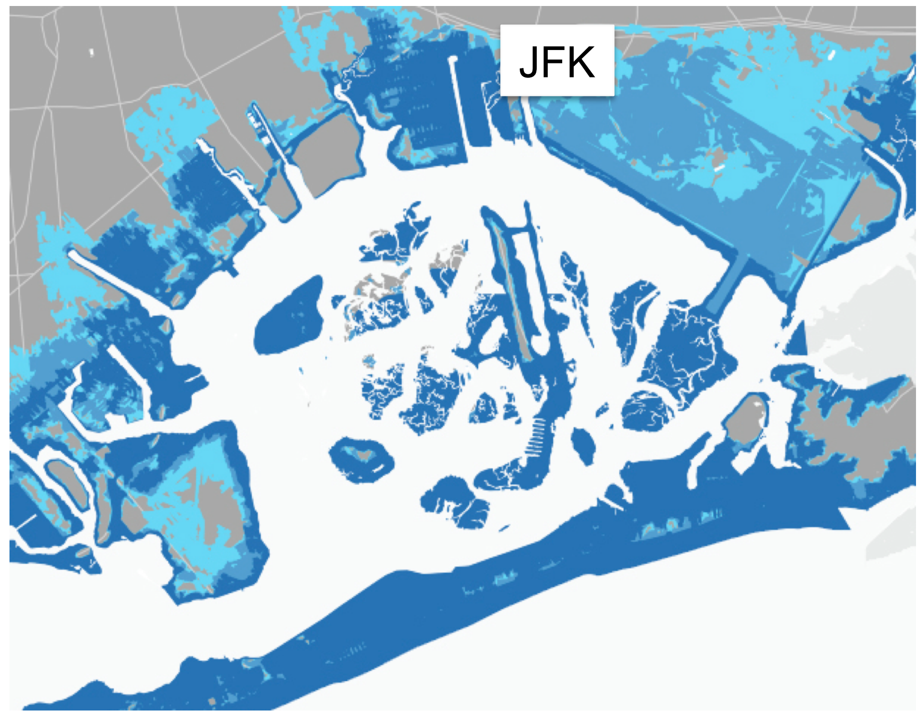
Level of Concern Regarding Impact Differs Across Subsectors

Sector Component	Infrastructure	Aircraft Performance	Passenger and Cargo Demand	Flight Safety	Passenger Comfort	Environmental Impact
Airports	High	Low	High	Moderate	Low	High
Airlines	Low	High	High	High	High	Moderate
ANSPs	High	Moderate	Low	High	Low	Low
Aircraft Industry	Low	High	High	High	Moderate	Moderate

Impacts on Airports Similar to Other Coastal Infrastructure

- Need: merge climate and infrastructure information on fine scale.



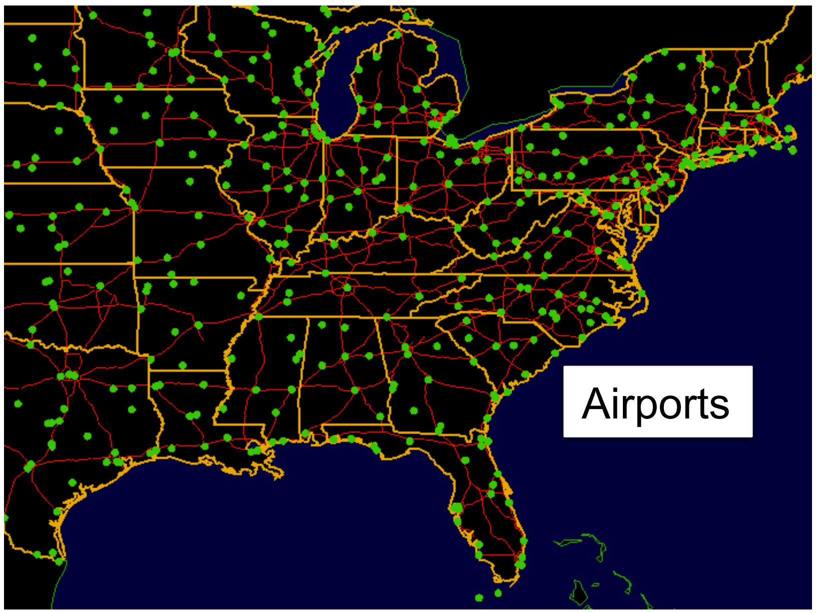


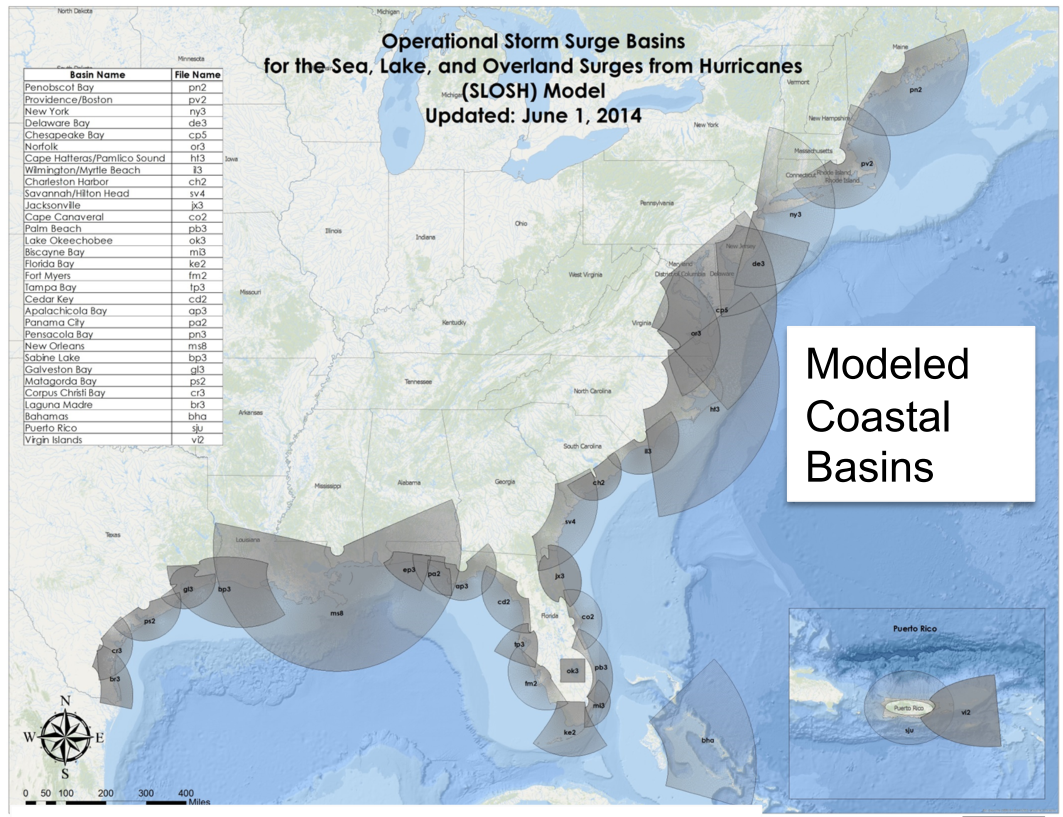
FEMA flood zone (June 2013)
2020s zone (11 inches of sea level rise)
2050s zone (31 inches of sea level rise)

See http://www.climate.gov/sites/default/files/NPCC100year_floodProj_large.jpg , based on New York City Panel on Climate Change, “Climate Risk Information 2013”, June 2013.

Impacts on Airports Similar to Other Coastal Infrastructure (Cont'd)

- Example: Greater detail for airports via NOAA SLOSH model.





SLOSH basins from http://www.nhc.noaa.gov/surge/slosh.php .

Must Understand Cost/Benefit Landscape in order to Define Needed Climate Services

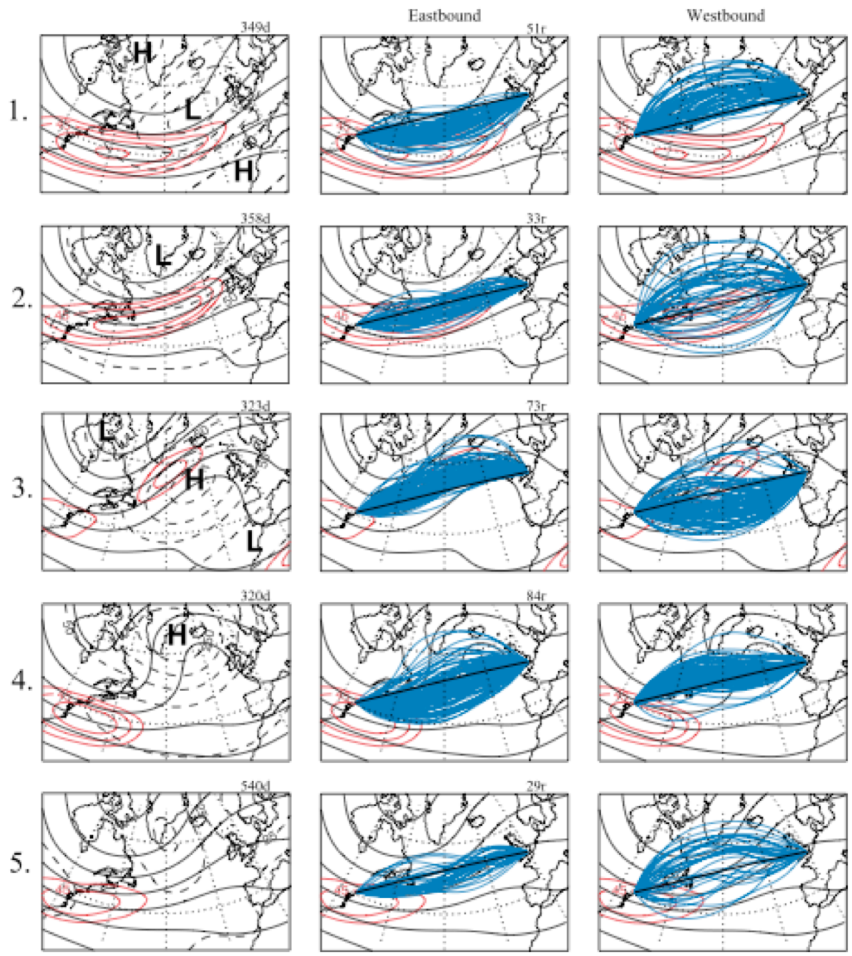
- Example: planning of route adjustments to reduce climate impact

Adjustment Type	Estimated Benefit	Estimated Cost
Systematic lowering of flight altitudes by 2000, 4000, and 6000 feet globally[6]	(1) Contrail RF in 2100 reduced by ~13%, 30%, and 48% compared with 2100 base case[7]. Same for global mean surface temperature increase related to contrails. (2) Total aviation RF in 2100 (incl. CO_2, H_20, O_3, CH_4) reduced by ~10%, 18%, and 26%[8] compared with 2100 base case. Essentially the same for global mean surface temperature increase for the combined effects.	Fuel increases by ~2.6%, 5.2%, and 5.9% globally.
Systematic lowering of altitudes with appropriate speed adjustments	(1) Contrail benefits should be the same as the first item above since speed does not affect contrail formation or persistence. (2) Combined total benefits would be higher due to fuel-saving speed adjustments.	Fuel increases should not be as large as above if speed is reduced as altitude is reduced in order to be close to the minimum in total cruise fuel at the lower altitude (similar effect if cost index is included). A rough order of magnitude estimate of the size of this effect is that the increases above would be lower by a factor of 2 or more.

- Route adjustments based on historical conditions shown.
- Different costs and benefits for adjustments based on current/predicted conditions.

How Climate Data Enters the Picture

- Need: historical patterns of region-specific weather conditions.



Five winter weather types for aviation over the North Atlantic* (3 summer types):

- Based on 1989-2010 ERA-Interim data and NAO/EA teleconnections
- Black contours - geopotential height anomalies at 250 hPa
- Red contours - 250 hPa wind speed above 40m/sec
- Heavy black line - Great-circle route
- Blue - actual trajectories

* Irvine, E. A., *et al*, “Characterizing north Atlantic weather patterns for climate-optimal routing”, Meteorol. Appl., 20, 80–93, doi:10.1002/met.1291, 2013.

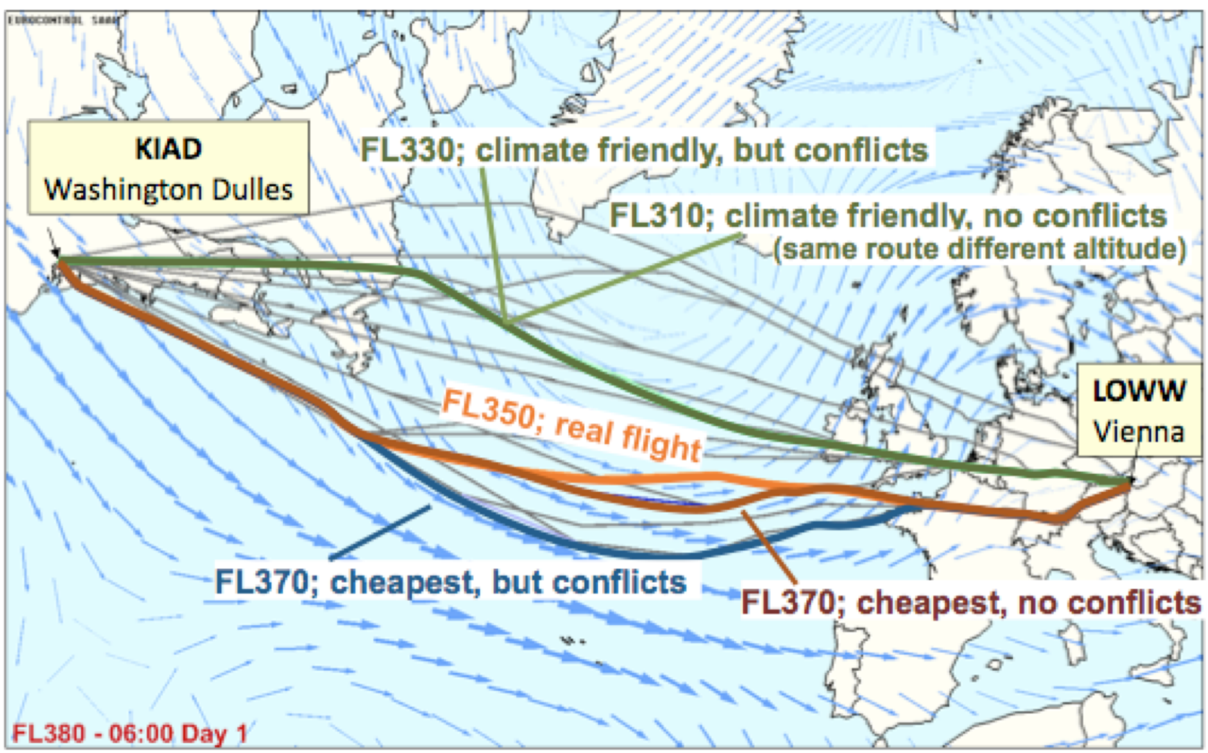
How Business Objectives Enter the Picture

- Minimal "cost" can be economic, climate*, or a combination of these.

Economic cost: $E_{ij} = fuel_{ij}$ (fuel cost) + $time_{ij}$ (time cost)

Climate cost: $C_{ij} = \sum_m \{fuel_{ijm} (M_{CO2ijm} + M_{H2Oijm}) + NOx_{ijm} (M_{O3ijm} + M_{CH4ijm} + M_{PMOijm}) + dist_{ijm} (M_{AICijm})\}$

*Total cost = A*EconomicCost + B*ClimateCost*



i and *j* refer to a particular pair of airports and *m* refers to a sequence of segments along each route.

M refers to climate costs for CO2, water vapor, ozone, methane, and aviation-induced cloudiness.

* V. Grewe, *et al,* "Aircraft routing with minimal climate impact: the REACT4C climate cost function modelling approach (V1.0)", Geosci. Model Dev., 7, 175–201, 2014.

Understanding Specific, Existing Risk Management Practices

- London Heathrow Airport risk-management process*:

Risks and Control Measures

Heathrow
Making every journey better

R	Significant
A	Moderate
G	Low

Risk ID	Risk	Climate Variable	Threshold	Confidence (climate projections and or consequences)	Risk Grading (no adaptation)	
					Short Term (to 2020)	Medium / Long (2020 to 2050s)
						AIRSIDE
1	**Flashpoint of aviation fuel exceeded on hot days** - potential fire hazard.	Temp	Aviation fuel flash point is 38°C. Temperatures during the summer of 2003 peaked at 37.5C	H	A	R
2	**Increased incidence of fuel venting** from aircraft in warm weather.	Temp	Aviation fuel flash point is 38°C.	H	A	A
3	**Increased fire risk** due to hotter temperatures combined with increased lightning and drought potential.	Temp	Requires research	M	G	A
4	**Change in distribution of pests and wildlife species.** Potential changes to bird migration patterns and bird strike risk.	Temp	Requires research	L	G	G
5	**Reduced lift** for departing aircraft due to 'thin air' and reduced engine efficiency in very hot weather.	Temp	Aircraft operate in multiple temp zones, unlikely to be breached	H	G	G
6	**Torrential rain creates hazardous conditions for vehicles and planes** i.e. airside and landside road vehicles, and taxiing and landing aircraft.	Precip.	Defined in Strategic Flood Risk Assessment (SFRA)	H	G	A
7	**Seasonal changes to fog related disruption** (increase in winter months, decrease for remainder of year).	Fog	Low Visibility Procedures when the Runway Visual Range (RVR) is < 600m and/or cloud ceiling is < 200 ft. Projections do not suggest any critical thresholds would be crossed	L	G	G
8	**Increased risk of schedule interruption** from stormy conditions.	Storms	High wind procedures and cross wind procedures enacted at defined criteria (dependent on aircraft type).	L	G	A
9	**Increased longevity of wing tip vortex effect** due to general becalming of surface wind speeds.	Wind	Wing tip vortex is particularly problematic for small planes taking off in quick succession after large aircraft.	L	G	G
10	**Change to prevailing wind direction affects runway utilisation** and schedules.	Wind speed/ direction	All commercial aircraft are tested to a "demonstrated" maximum crosswind as part of their certification. Large aircraft are better able to handle cross winds than light aircraft. Technology is improving all of the time.	L		
11	**Disruption to airfield operations from lightning** i.e. refuelling suspension, changes to flight routing.	Lighting	All commercial aircraft are tested for resilience to lightning strike as part of their certification. Planes can withstand lightning strike in the air but during take off and landing instrument loss would be critical hence the diversion of routes and stacks.	L	G	A

1. Identify risks and potential consequences from climate change;
2. Estimate likelihood of the consequence on a five-level scale for the short, medium, and long term;
3. Estimate severity of the consequence on a five-level scale for the short, medium, and long term;
4. Establish risk priorities on a three-level scale based on likelihood and severity the short, medium, and long term;
5. Evaluate adequacy of any risk-control measures already in place
6. Evaluate uncertainty/confidence associated with climate projections on a three-level scale;
7. Define required adaptation responses (taking action, making plans, monitoring) based on the above.

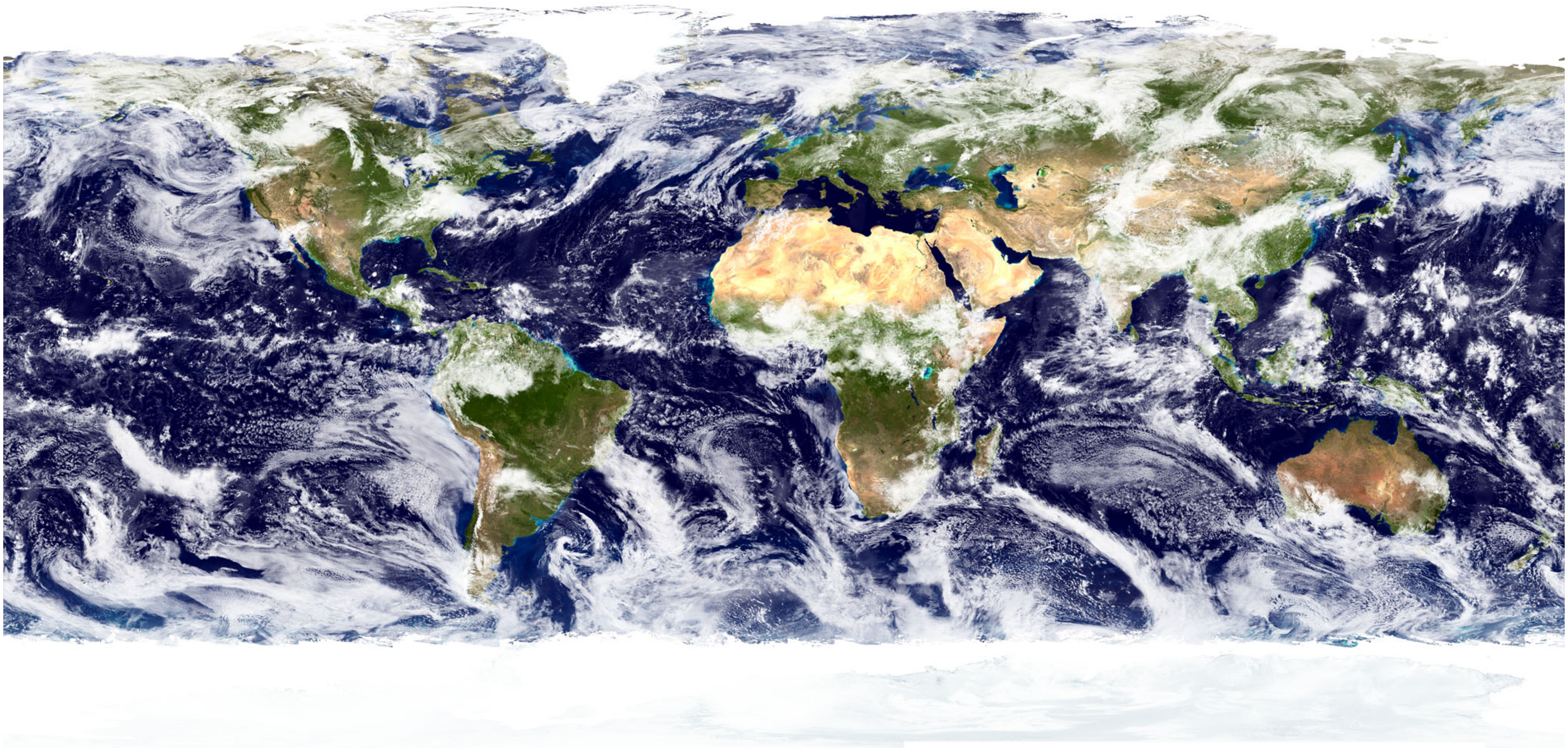
* Heathrow Airport, "Climate Change Adaptation Reporting Power Report", May 2011.

Complexities in Application of Climate Services to Commercial Aviation

- Data availability (and complexity) exploding.
- Different levels of understanding and uncertainty for various climate effects, particularly at high spatial resolution.
- “Commercial air transport” is not a single user community.
- Business focus is near-term.
- Risk-management needs are specific to each sub-sector and depend on complicated and differing business contexts.
- Need better decision-making under uncertainty on timescale of years to decades.

Key Challenges

- Identifying what types of climate data are most relevant the different decisions facing the several segments of this industry
- Determining decision-appropriate time horizons and spatial resolutions for forecasts of this data
- Coupling the uncertainties inherent in these forecasts to the decision process.



Questions?

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